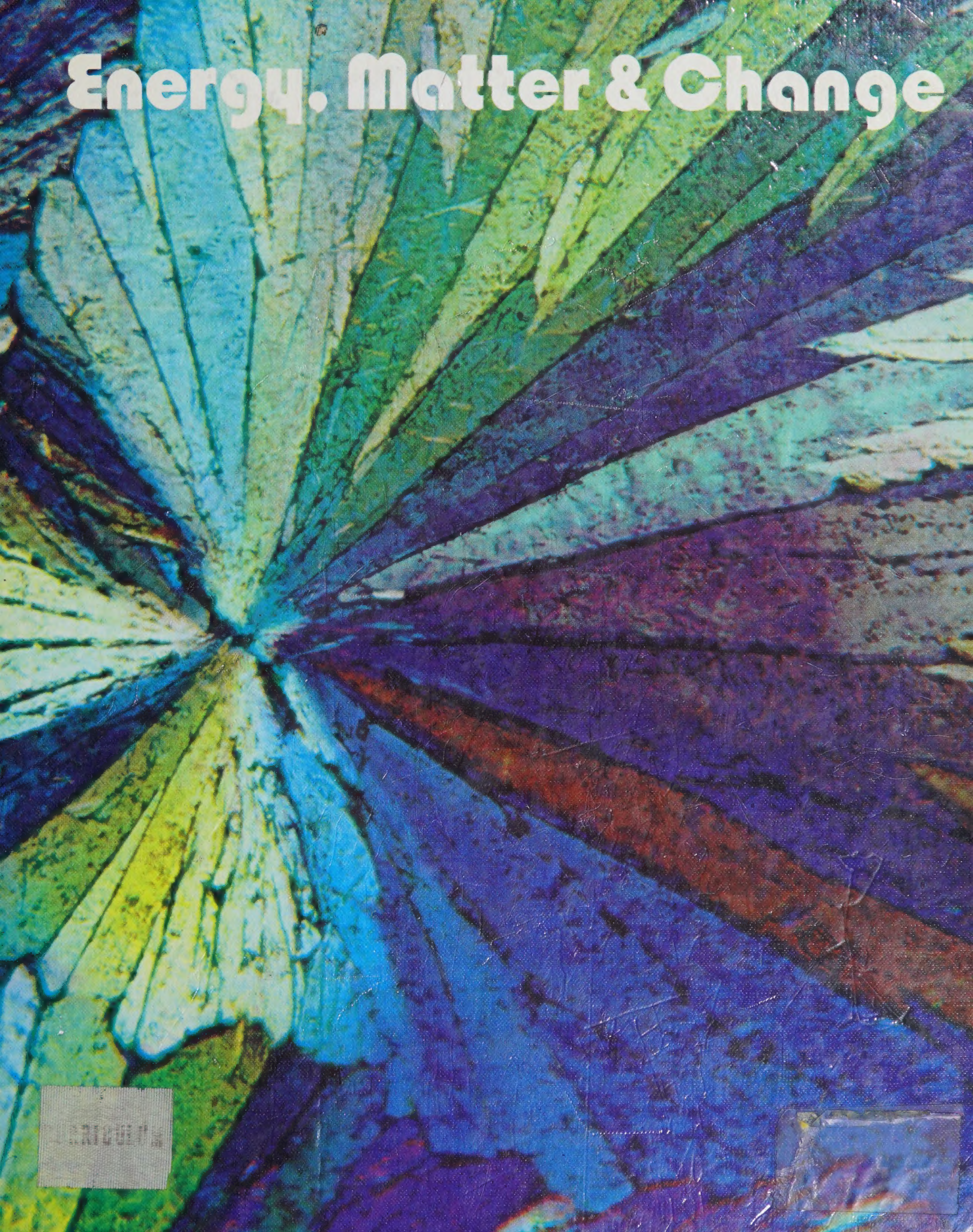
Energy, Matter & Change



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Energy, Matter, and Change

Excursions into Physical Science

Ronald D. Townsend

Paul DeHart Hurd
Senior Consultant

Scott, Foresman and Company

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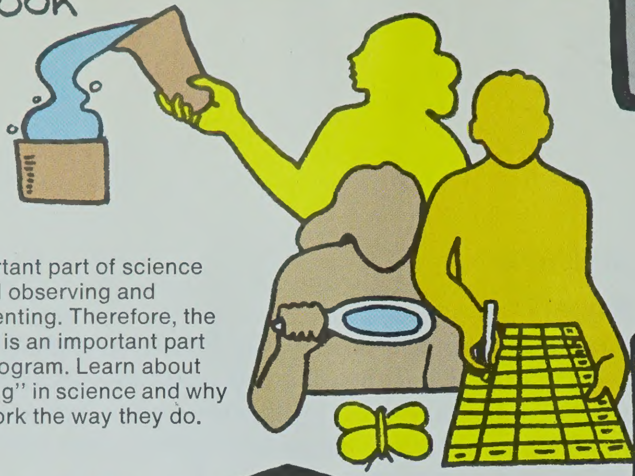
LAB BOOK



An important part of science is careful observing and experimenting. Therefore, the lab book is an important part of this program. Learn about the "doing" in science and why things work the way they do.

NOW MOVE TO THE SUGGESTED FOLLOW-UP READING IN THE TEXT...

WHEN NECESSARY, YIELD TO THE LABORATORY BOOK... DO THE ASSIGNED ACTIVITY.

CHAPTER OPENER

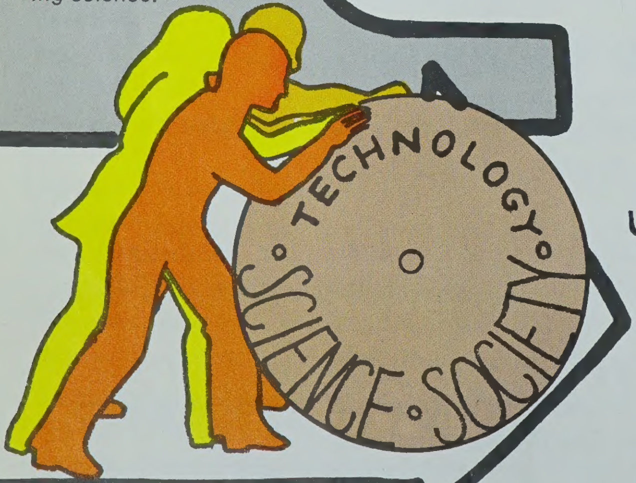
Chapter 1: Why Color?

1

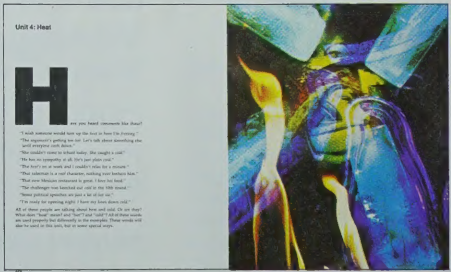
Watch for these. They tell you what topic is coming up.

START HERE

To the student: your study guide to *doing*, *reading*, and *discussing* science.



UNIT OPENER

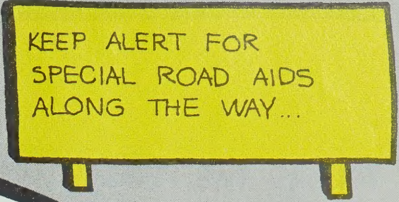


Unit 4: Heat

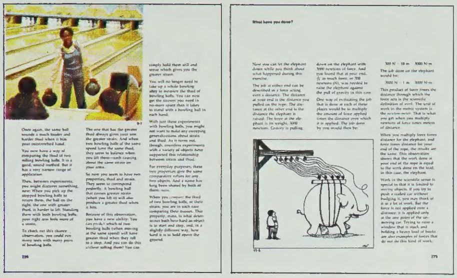
H

There are five units in this learning journey . . . light, electricity, motion, heat, and chemistry.

Keep the wheel moving. Apply your mental and physical energy. The goal—*a different way to view your world.*

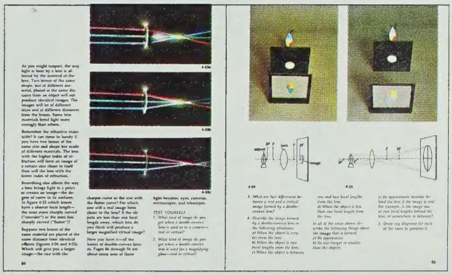


MAIN TEXT

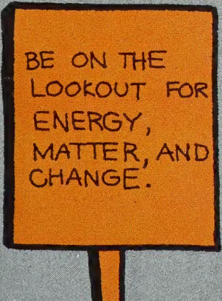


For easier reading, the material in the main text—the basic path—is in narrow columns. You can't miss it. Visit those special features in the book that branch off this path.

PHOTOGRAPHS AND DIAGRAMS

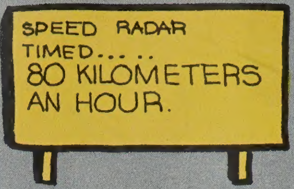


There are special kinds of photographs and diagrams. Observe what is happening in the photographs. Make some judgments and predictions about the experimental situations. Use the diagrams to help you explain observations and to compare ideas.



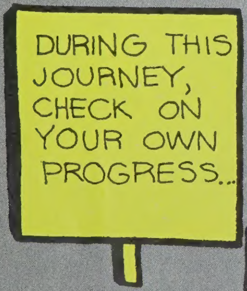
THINK METRIC

Go to page xiv. Then turn right to Appendix A. Use the tables provided. Practice using the world language of measurement. The metric system has already become more widely used in the U.S. Find out why in the essay on page 242.

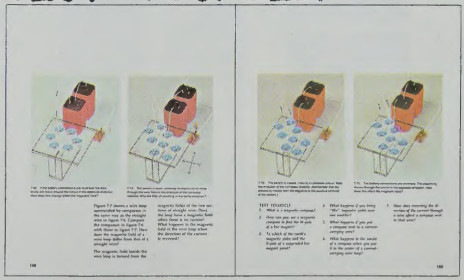

SPEED RADAR
TIMED.....
80 KILOMETERS
AN HOUR.

JUST FOR FUN.

Don't miss this special feature. You will know these pages when you see them.



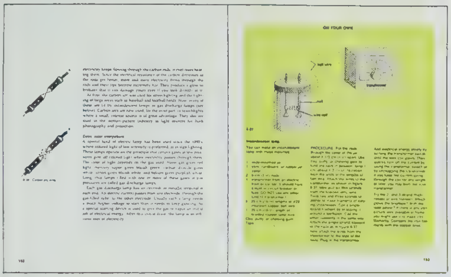
TEST YOURSELF



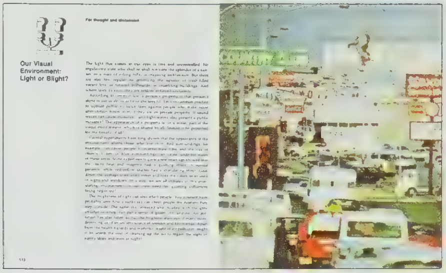
What important ideas did you get from reading the main text? After you answer the questions, turn to Appendix B. Compare answers.

ON YOUR OWN

Observe, measure, control variables, and *interpret data* with simple materials from the supermarket or hardware store.



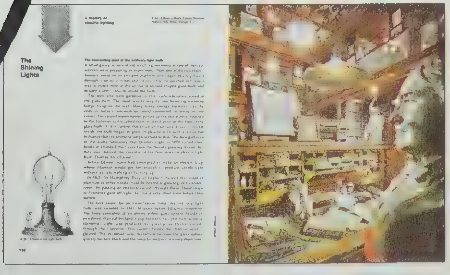
THOUGHT AND DISCUSSION

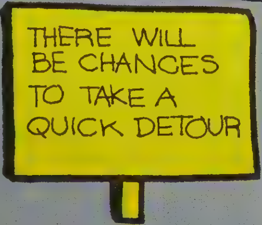


Each unit ends with a section called "For Thought and Discussion." Look for the symbol. Stop here awhile. We know science and technology have made our lives more comfortable. Yet, there are many problems science and technology *alone* can not solve. These readings identify some of *our* current problems and ask for your opinion.

ESSAYS

Watch for the gray arrow. There you'll find more on theories and the history of science, scientists, the future of science and technology, and how all of these affect you. Go to Appendix C for review questions on each essay.




THERE WILL BE CHANCES TO TAKE A QUICK DETOUR

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BEFORE YOU BEGIN . . .

Learn a little more about the METRIC SYSTEM of measurement before reading the text and doing the lab work.

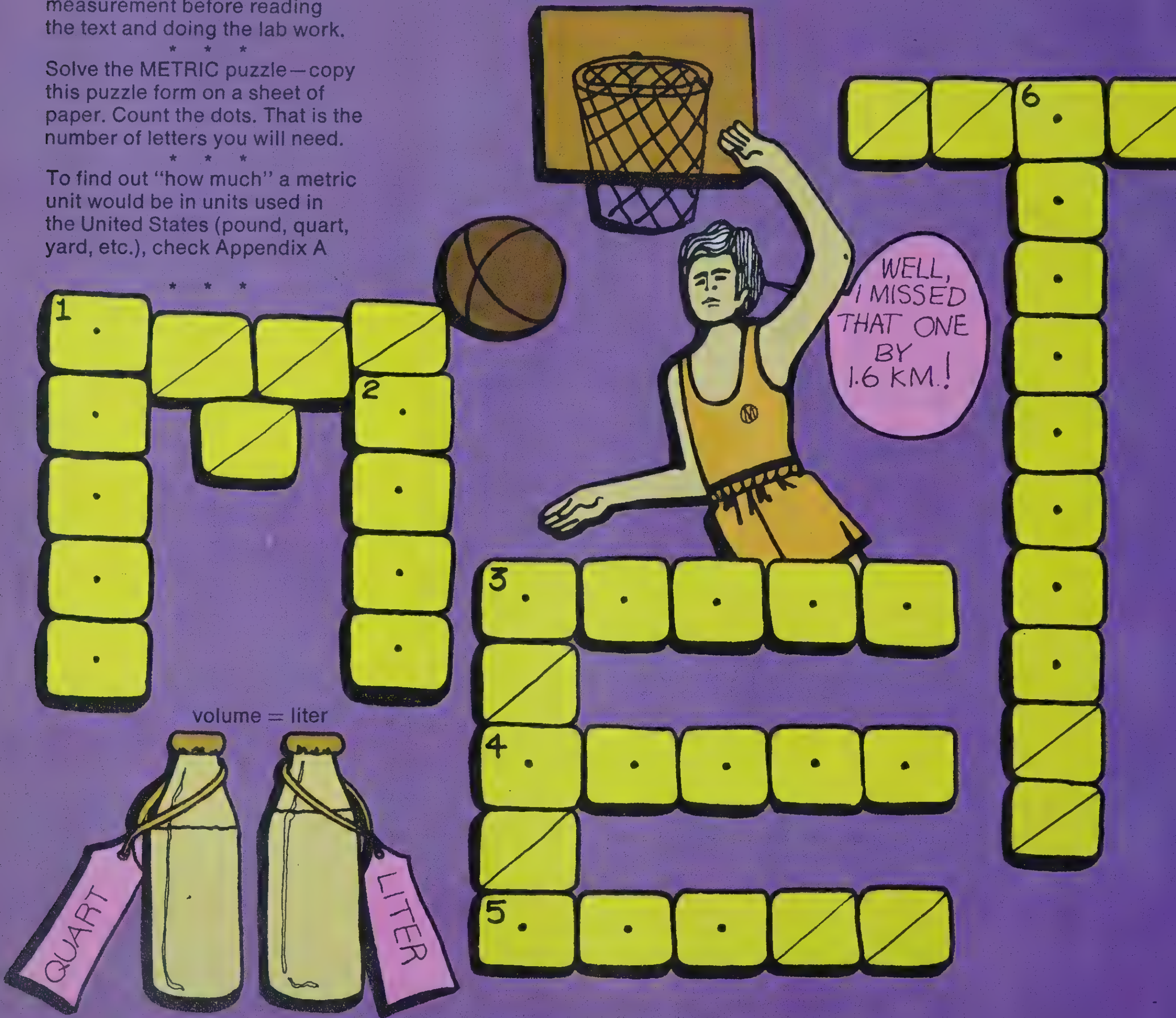
* * *

Solve the METRIC puzzle—copy this puzzle form on a sheet of paper. Count the dots. That is the number of letters you will need.

* * *

To find out "how much" a metric unit would be in units used in the United States (pound, quart, yard, etc.), check Appendix A

* * *

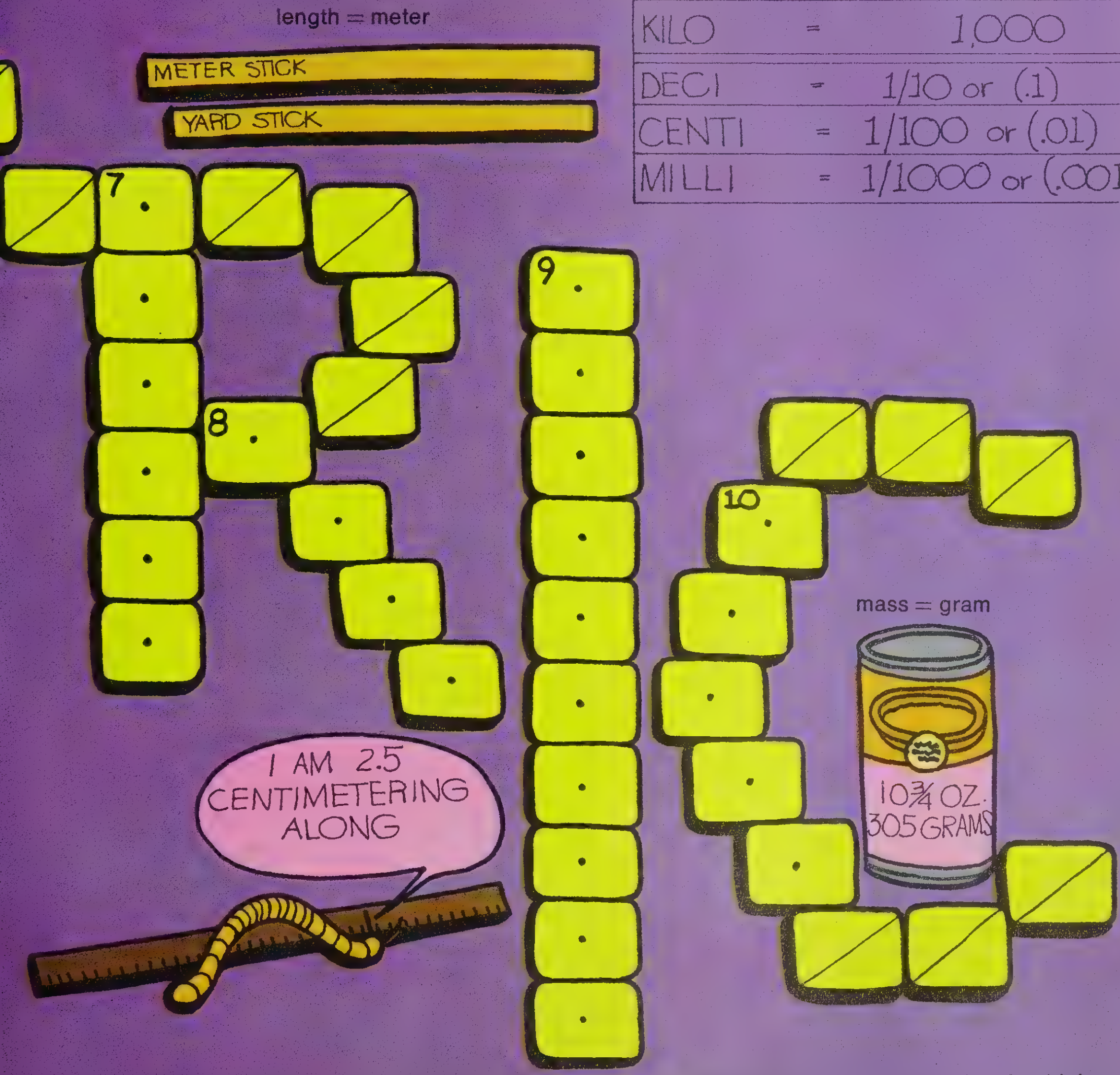


Look at clues on these pages to solve the first three problems.

1. What basic metric unit is used for measuring *length*?
2. What basic metric unit is used for measuring the *mass* of something?
3. What basic metric unit is used for measuring *volume*?
4. To measure something *less than* a meter, a liter, or a gram, just add a prefix to the basic unit. When you add milli- to gram you have a milligram (worth 1/1000 of a gram). What would the prefix be that is 1/100 or .01 of a meter? (Use the table.)
5. The magic number in the metric system is ________? (Need help? Check Appendix A.)

BASIC TERMS: METER, GRAM, LITER

PREFIXES ——→		VALUES
KILO	=	1,000
DECI	=	1/10 or (.1)
CENTI	=	1/100 or (.01)
MILLI	=	1/1000 or (.001)



6. To measure something *more than* a meter, a liter, or a gram, just add a different prefix. If something is more than one gram, it would be a ________?

7. If a distance is one kilometer, it would be equal to 1000 ________?

8. This system of measurement is *e— —y*!

9. You want to express how much space is occupied by some soup in a soup spoon. What is the smallest metric unit you could use? (Check the table.)

10. To describe the thickness of this page you would use the basic term meter. What prefix would you add to it?

Unit 1: Light

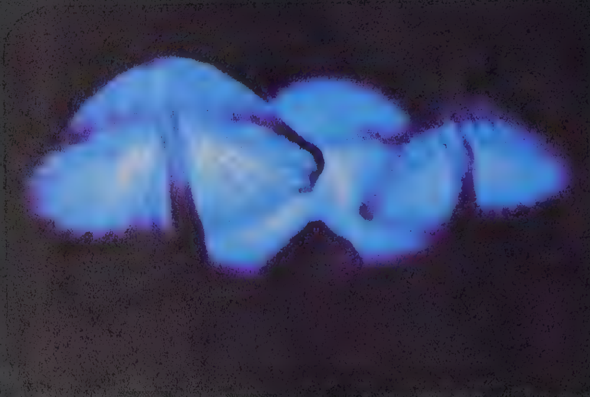
Try your luck! Knock over the milk bottles and win yourself a prize!” shouts the carnival barker as he holds out three battered baseballs. The barker in the next booth is shouting something about tossing a hoop on any prize you want. You wouldn’t mind trying either one. But you have a hot dog with the works in one hand and a bag of popcorn in the other.

Suppose someone sneaked up on you and blindfolded you right then. What could you still tell about what was going on? You could hear the shouts of the carnival people, the jumbled noise of the crowd, and the creaking of the Ferris wheel. You could feel people moving past you by the slight movement of air. And you could smell and taste the popcorn and the hot dog. But what a difference from seeing it all!

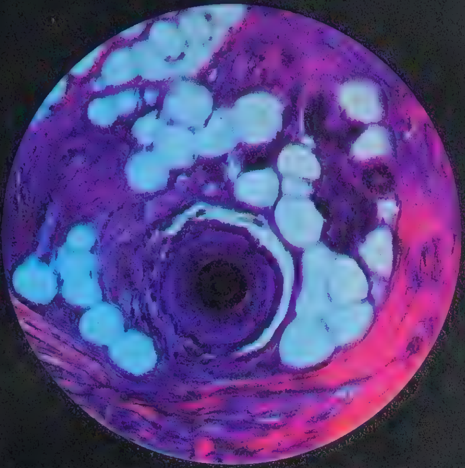
If there were no sun, light bulbs or neon lights, candles, or anything else that gives off light, you wouldn’t have much luck knocking milk bottles over with a baseball at a carnival. You couldn’t see the faces of your friends and they couldn’t see you. There would be no movies or television. Scientists could only guess about the world of tiny bacteria because there would be no microscopes. And they certainly would know very little about the moon or anything else in space because there would be no telescopes. There would be total blackness.

Niagara Falls

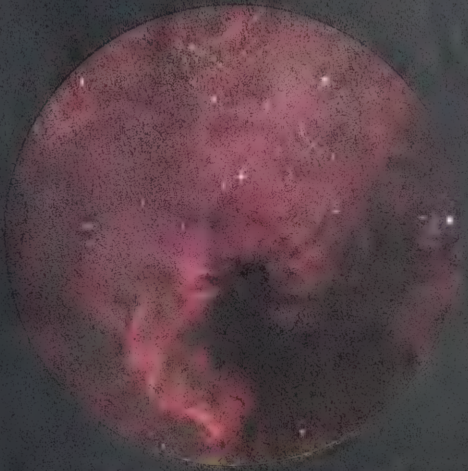
a. There are many sources of light. The one we rely on the most is, of course, the sun.



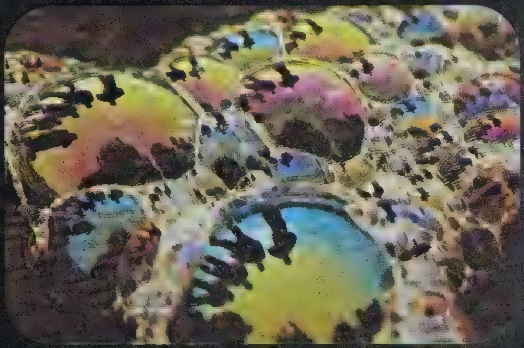
b. There are also some very unusual sources of light, such as this tiny light-giving plant. It is a type of fungus which grows on tree bark or on decayed wood. The diameter of the cap is 20 millimeters. The length of the stem is about 25 millimeters. This fungus was found on an island near Japan. When many of these tiny plants cover a tree branch, they look like many bluish fireflies all turned on at once.



c. This is a section of scalp tissue as seen through a microscope. Separate cells show up as does a cross section of a hair root. The hair root is the dark spot in the middle. Without a microscope, an instrument which needs light, microscopic things such as the cells in this scalp tissue, could not be studied.



d. Another instrument which depends on light is the telescope. It gathers light from stars and other objects at great distances in space. This photo, taken through a telescope, shows a nebula which has the shape of North America. A nebula is a cloud of cosmic dust and gas.



e. Light can cause some interesting effects. These individual bubbles of sea foam are reflecting people standing above it. And though the bubbles themselves have no color, the light they reflect looks colored.

f. In daylight this singer would not have such a golden glow. The spotlights shining on her give her that look.

Chapter 1: Why Color?

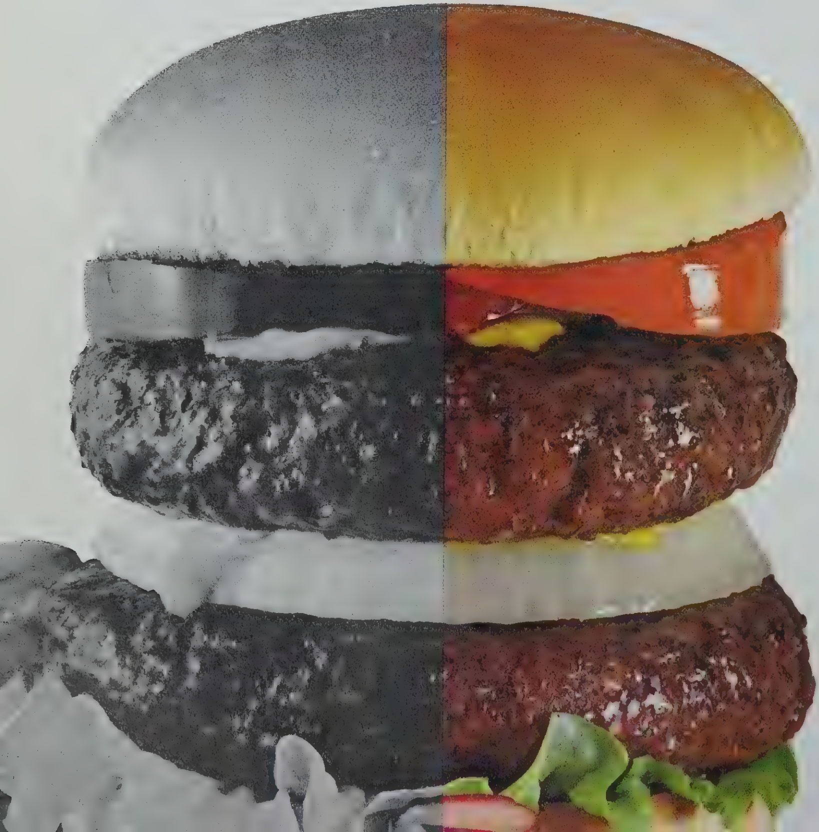
1

How would you like a gray hamburger? That's what you would get in a world of black, white, and shades of gray. The lettuce, tomato, and the catsup would also be gray. Grass, trees, and flowers would be gray.

However, deciding what to wear would be simple. Everything would go together. It would also be a snap to choose colors for furniture, houses, and cars. You could have your pick of black, white, or any shade of gray. And you wouldn't need color photographs, movies, or television—not in a world of black, white, and gray.

But the world does have color. A hamburger in color can make your mouth water. Bright clothes can make you look and feel good. And movies and television shows in color are more lifelike than the same ones in black and white.

This section is about color—that quality which makes the world more interesting to look at.



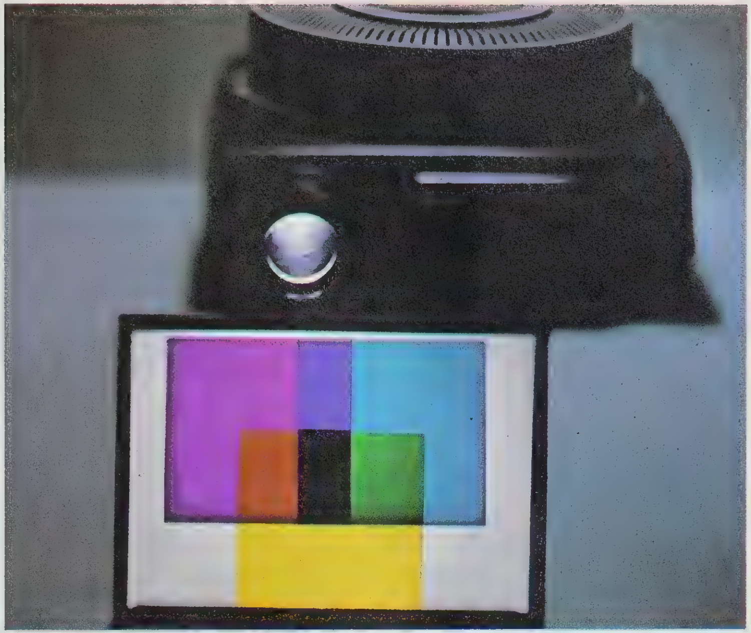
Does "colorless" light contain color?

When you think of light, your first thoughts may be of reading lamps, sunlight, flashlights—mostly light that seems to have little or no color. The light leaving the projector in figures 1·1 and 1·2 also looks colorless or white.

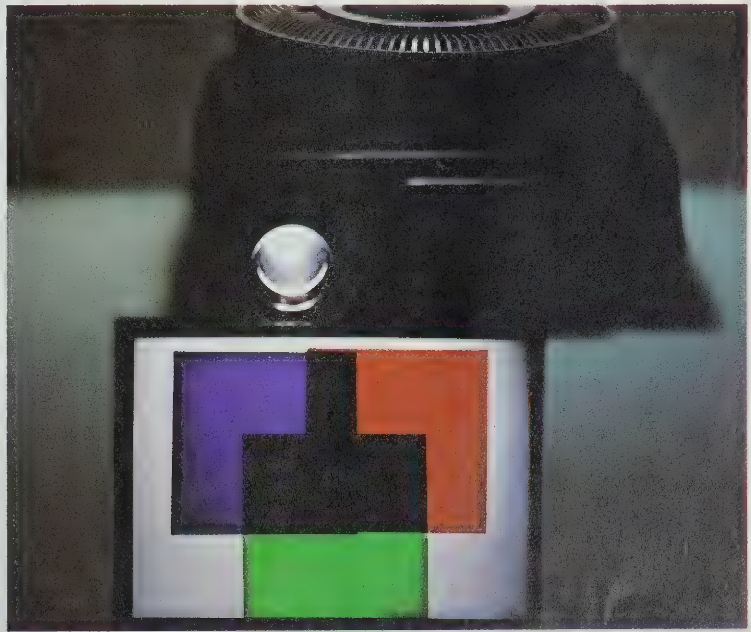
Notice what happened when that white light passed through the colored sheets on the stand. At first glance the sheets may not seem transparent. But they are. Wherever two colored sheets overlap, you see the color of the light that passed through both sheets. You see red where the light passed through the yellow and magenta sheets. You also see red where the light passed through just the red sheet.

This raises some interesting questions. Do the transparent sheets *add* color to the light? Does the red sheet add red to the white light? And why do you see what you do where two of the sheets overlap? You can do some observing to answer these questions.

You may have seen at some time that the colors of the rainbow appear after light passes through a *prism*. The band of colors—called a *spectrum*—has red, orange, yellow, green, blue, indigo, and violet.



1·1 Transparent magenta, cyan (blue-green) and yellow sheets overlapping. Notice the results where the sheets overlap.



1·2 Transparent blue, red, and green sheets overlapping. No light passes through where these sheets overlap.

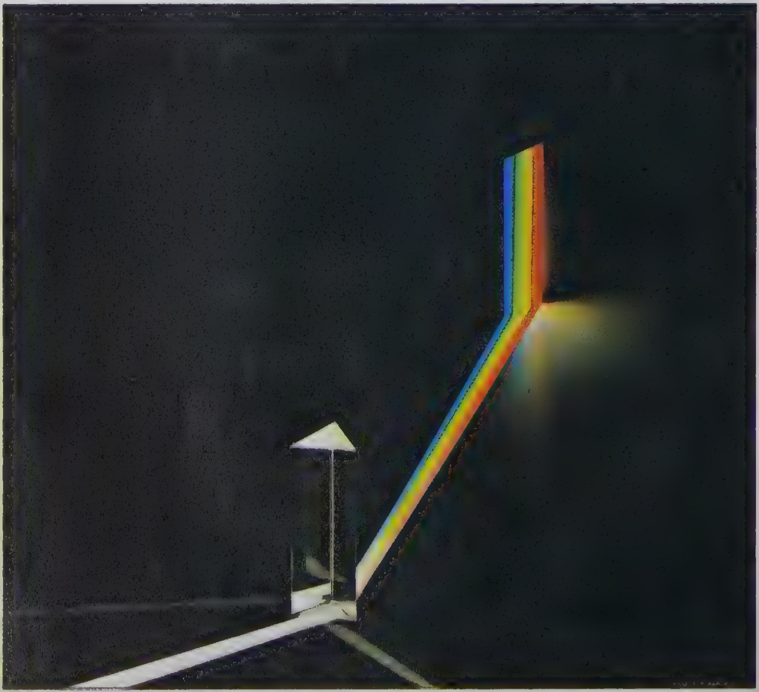
Unless you have a very good prism and very bright white light passing through it, you won't see all these colors. If the light is at all whitish looking before passing through the prism, you will probably be able to see the *red, green,* and *blue* areas of the spectrum. You'll often also see some yellow. The red area contains the red, orange, and a little of the yellow. The green area contains green, some yellow, and a little blue. The blue area has most of the blue and all of the indigo and violet.

Because the red, green, and blue areas are the ones which stand out the most, the study of the color spectrum is easier if, in most cases, we just consider these three sections. But sometimes we will also include yellow.

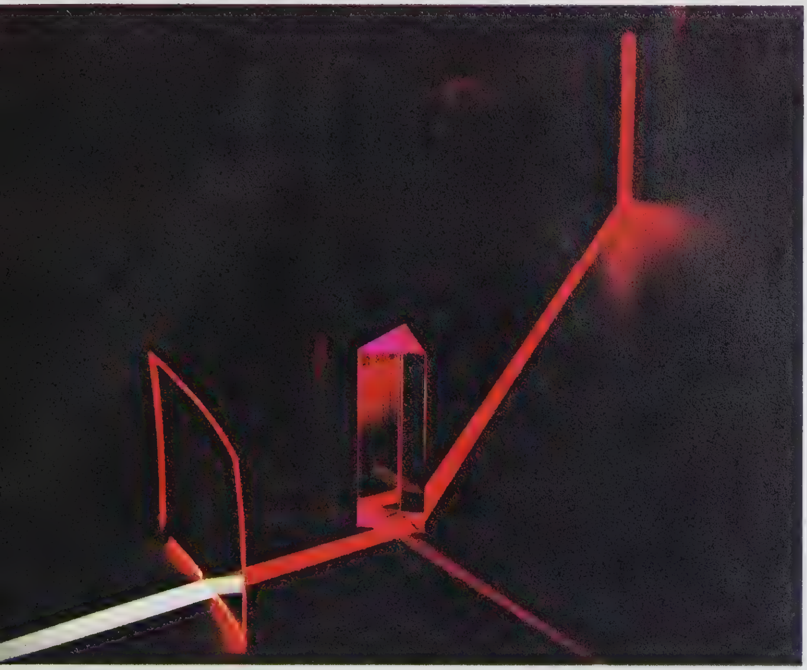
Instead of a prism, you can also use a small plastic sheet with many fine lines scratched in it to get a spectrum. This kind of sheet is called a *diffraction grating.* Some gratings produce colors when light passes through them. Other gratings produce colors when light is reflected from their surface.

At this point you have two observations to work with. First, you see that a red transparent material, when it is put in front of a white light, seems to change the white light into red light. The blue sheet makes its area of the white light look blue. And the green sheet makes its area of the white light look green. From these results, try to state what effect, in general, a colored transparent sheet has on white light going into it.

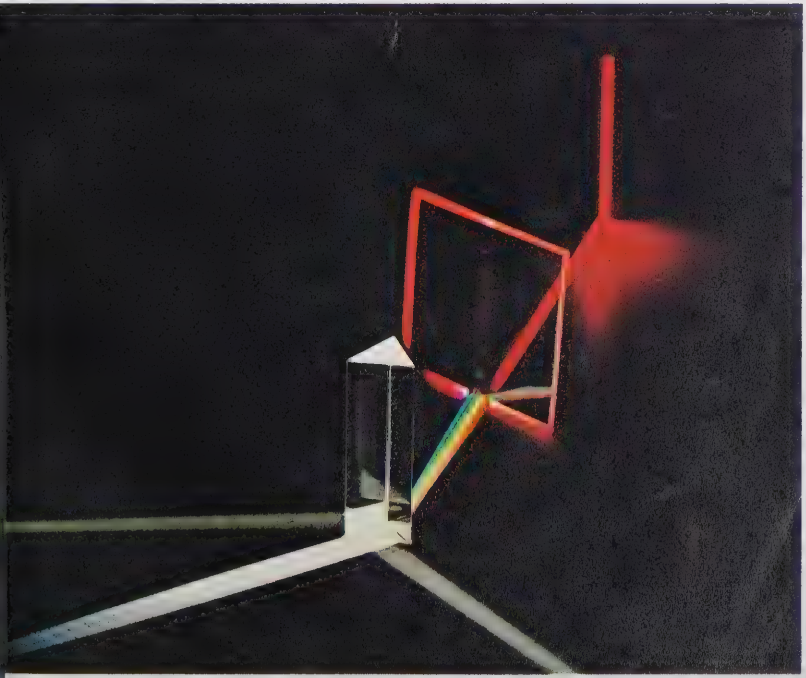
Second, you saw that a prism or a grating can be used to produce a rainbow of colors, a spectrum, from white light. Now put these two observations together. Notice the results when a transparent colored sheet is placed in the path of a white light before and after it passes through a prism (figure 1·4).



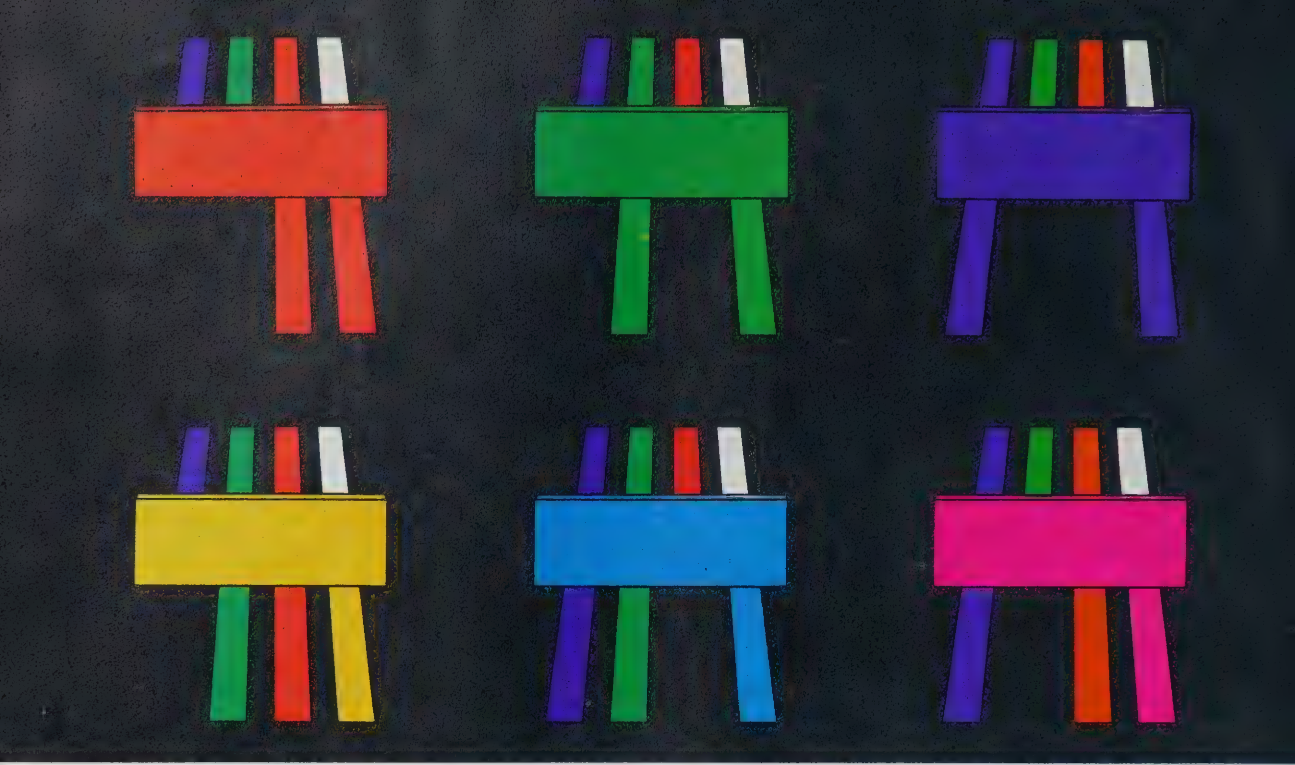
1·3 Blue, green, and red are the major color areas of the spectrum produced from white light.



1·4a A piece of red transparent material in the path of white light before the light enters a prism.



1·4b A piece of red transparent material in the path of white light after it has passed through a prism.



1·5 Blue, green, and red bands of the spectrum and a beam of white light are striking red, green, blue, yellow, cyan, and magenta filters. Notice which band(s) each filter stops and which band(s) each filter lets through. Also notice what happens to the white beam in each case.

To explain the way the colored sheets act on light, consider the idea of a filter. A *filter* is something used to separate the parts of a mixture. For example, if you have sand mixed with water, you can separate the two by pouring the mixture through a paper filter. The water will go through. The sand will stay in the paper.

The transparent colored sheets are called color filters. Why is that a good name for them? Does it look like the transparent sheets add or take away color from the white light? Once you have decided that for yourself, you can answer the question "Does 'colorless' light contain color?"

TEST YOURSELF

1. *What are the parts of a white-light spectrum?*
2. *What two devices can be used for breaking white light into its parts?*
3. *Construct a table of all the color filters shown in figure 1·5. Give the spectrum colors that pass through each. Also name the major color areas of the spectrum (red, green, and blue) which are blocked by each filter.*
4. *Use the table you made for question 3 to predict the colors of the spectrum that will pass through two overlapping filters in each of the following combinations:*
   - *a) red and yellow filters*
   - *b) cyan (blue-green) and green filters*
   - *c) blue and yellow filters*
   - *d) blue and green filters*
   - *e) magenta (red-blue) and red filters*
   - *f) magenta and yellow filters.*
5. *Name two filters which in combination block all the colors of the spectrum. Then name two more pairs of filters which do the same thing.*

Newton's particle theory of light applied to the visible spectrum

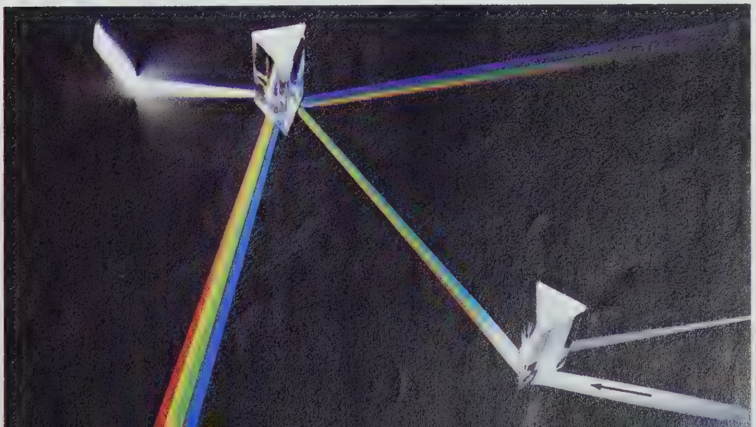
What Is Light? Part 1

Particles of light

The question "Does light have color or can something add color to light?" is an old one. At first you might have thought that color filters add color to light. In the same way, it is reasonable to think that a prism adds color to light. However, over 300 years ago, Isaac Newton, the English scientist, suggested that white light is a mixture of colors. He did experiments to prove his point. He used a prism to produce a spectrum from sunlight. He then reasoned that another prism should recombine the colors into white light. He was right; it works. However, he had to have the light come in at exactly the correct angle and have the prisms at exactly the correct angle to each other to get his results.

Newton's observations aroused his curiosity. He wondered what light really is. After some thinking and more experimenting, it seemed possible to him that light is made up of invisible particles in motion. Each color in light could consist of particles different from those of other colors. A prism just separates them.

This particle theory is useful in explaining color filters. You can think of color filters as letting through some particles of light and not others. For example, a red-orange filter lets through red, orange, and perhaps some yellow light particles. But a green filter blocks these same particles. So when a red filter is placed on top of a green filter, most of the light particles are stopped. You can not see much through both of them together.



1·6 The first prism is separating a beam of white light into a spectrum. The second prism is recombining part of that spectrum into white light. The prism reflects the rest of the spectrum sideways.

In green light
will a "red" object be red?

This page with its photographs and black type, your coat, and a brick wall all block light. Surfaces which block light are called *opaque.* Such surfaces absorb some of the light. For example, you might have guessed that you have absorbed some light when you begin to feel warm after sitting in the sun.

But opaque surfaces also reflect some of the light. As a matter of fact, that's the reason you can see them. For instance, you see this page because it reflects light.

You have also seen that the nearly white light of the sun or of a projector is made up of the colors of the rainbow. What do you think happens to the colors in white light when they hit opaque surfaces? Are the colors reflected or absorbed?

Notice the change in color of the objects in figure 1·7. The first column of photographs was taken under an ordinary photographer's spotlight. A spectrum of that light would show all the colors of the rainbow. The second column of photographs was taken under a spotlight with a red filter in front of it. The third one was taken under a green light. The fourth one, under a blue light.

Notice that the truck which looks red in white light also looks red in red light. But in green light the same truck looks almost black.

You can use what you have learned so far to figure out why you see the colors you do in figure 1·7. Remember color filters pass some colors of white light and block others. Opaque materials *reflect* some light and absorb some.

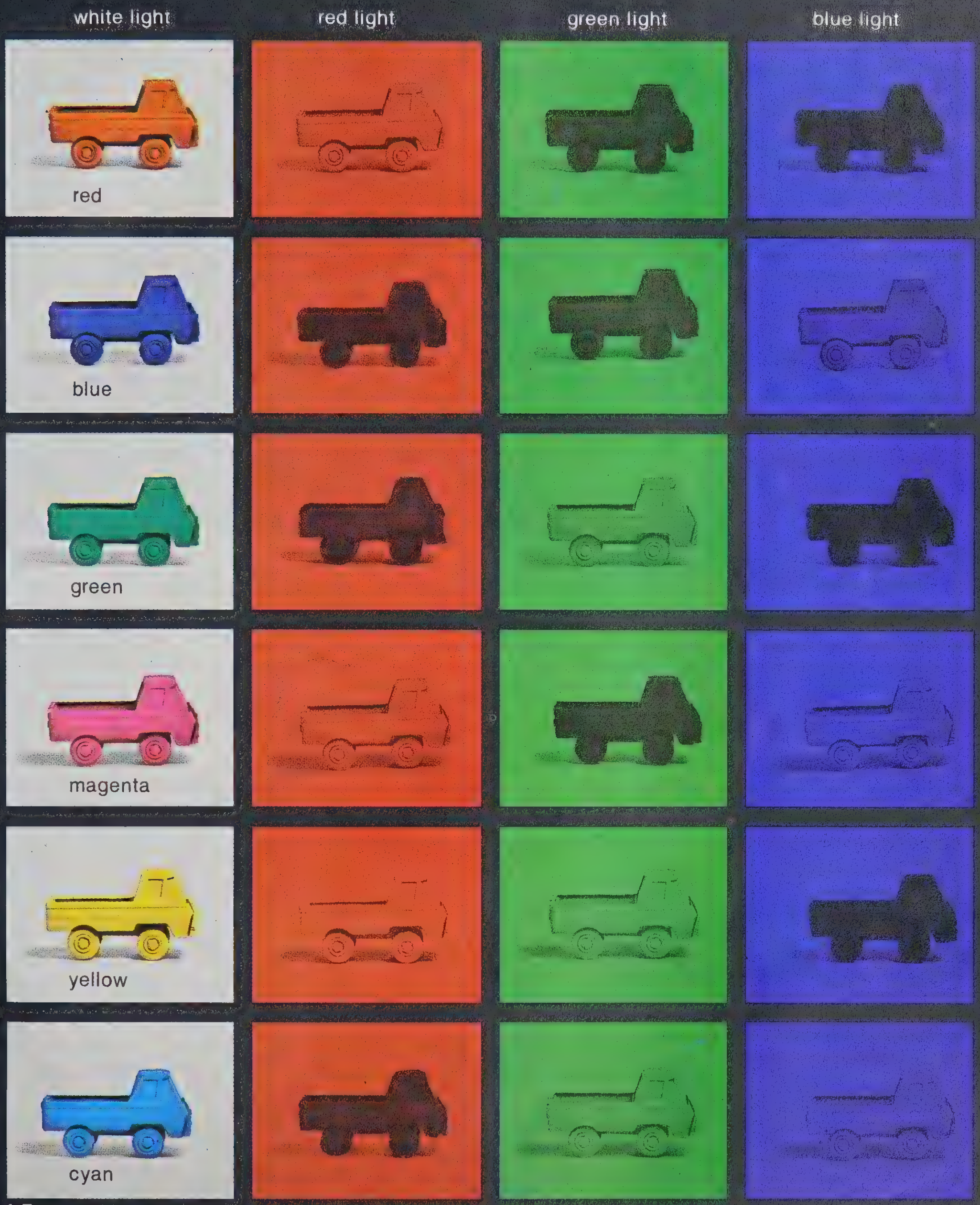
For example, when a red filter is placed in front of the light, the red area of the white light spectrum passes through. Most of the other colors—including green—are blocked. On the other hand, a red opaque surface reflects a part of the spectrum and absorbs others.

Which section of the spectrum—the red, green, or blue—do you think a red surface reflects? That is, which section bounces off the surface and reaches your eye so that you see red? Which sections of the spectrum do you think it absorbs? Try this same reasoning for the other colored surfaces.

The chart of colors you made for question 3 on page 10 and figure 1·5 should also help you understand why you see the colors you do.

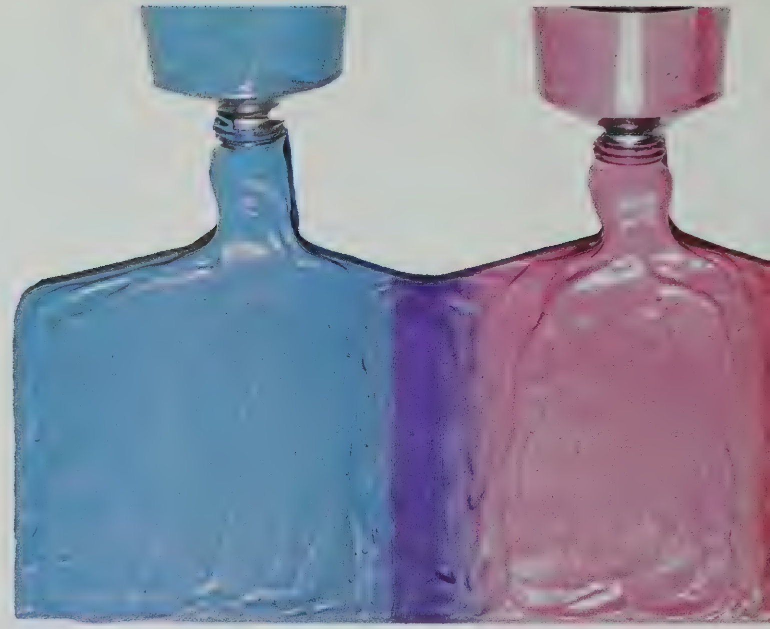
The coloring matter of opaque materials often contain colors other than their main color. Usually our eyes do not notice these small amounts of other colors. However, these can interfere with making exact observations and conclusions.

In a very well controlled laboratory experiment, a blue opaque surface under a red light should look completely black. But the red light would have to be a pure red and the blue surface a pure blue. So in your mental models of these observations, make room for the real world.


white light
red light
green light
blue light
red
blue
green
magenta
yellow
cyan

1·7

What is it about a tomato that makes it red?



1·8

When you are deciding what to wear, can you think about your clothes without thinking of their color? Can you think about strawberry ice cream without thinking pink? Or a ripe tomato without thinking red?

By now it probably makes sense to you to think that you see an object, such as a ripe tomato, as red because that object reflects the red portion of light. But what is it that causes it to reflect the red portion of light?

You know you can use paints or dyes to "give color" to the surface of things. Things in nature, such as rocks and plants, have their own natural color. The particles of matter that cause the color you see in paints and dyes and the color particles found in other objects work in much the same way.

The structure of each color particle causes it to reflect some of the colors in light and to absorb others. For example, the color particles in chlorophyll (the substance that gives green plants their color) reflect green and a little red. But these color particles absorb blue and violet.

You need only three pure colors of paints or dyes—and very exact mixing—to reproduce any color in nature. A pure dye is one which reflects light from selected sections of the spectrum, with only traces from other sections of the spectrum.

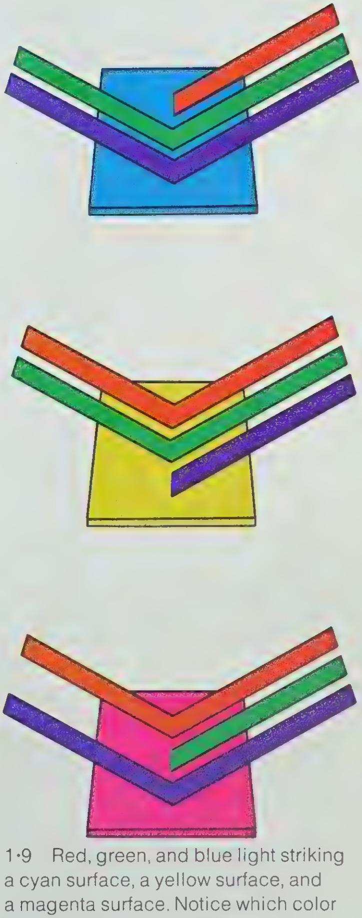
Magenta (red-blue), yellow, and cyan (blue-green) are the three basic colors of paints or dyes. Each reflects two major parts of the spectrum and absorbs most of the third. You can get green by mixing pure cyan and yellow paints; red, by mixing magenta and yellow; and blue, by mixing cyan and magenta (figures 1·8 and 1·9).

Since pure paints are rare, you will usually not get a pure green, red, and blue when you mix paints this way.

If you want a lighter or darker shade of any color, you can mix in white or black. You can get all other colors by mixing different amounts of any two or three of these pure paints. By mixing all three paints in about equal parts you can get black or muddy brown. The cyan paint absorbs the red area of the light spectrum. The magenta paint absorbs the green area. And the yellow paint absorbs the blue area. You can see that there isn't much left to reflect, so the eyes see only a dark spot of paint.

TEST YOURSELF

1. *If a pure red spotlight is shining on fried "sunny-side-up" eggs, what color will the yolks appear to be? Why? Explain your answer in terms of the colors the yellow in the yolk can reflect.*
2. *If a pure green spotlight is shining on a green plant, what color will the plant appear to be? Explain your answer. Hint: Green plants need light in order to grow. But green light is about the poorest light for a green plant.*
3. *Explain how the mixing of yellow and cyan paints produces the color green under white light. Give your answer in terms of the spectrum colors reflected and absorbed by each paint.*
4. *What do you think you will see when you shine a pure blue light on a mixture of equal parts magenta and cyan paints? Explain your answer.*



1·9 Red, green, and blue light striking a cyan surface, a yellow surface, and a magenta surface. Notice which color bands are reflected or absorbed by each colored surface.

Black-and-White Photography and Printing

Examine the dot pattern in this photograph with a magnifying lens.

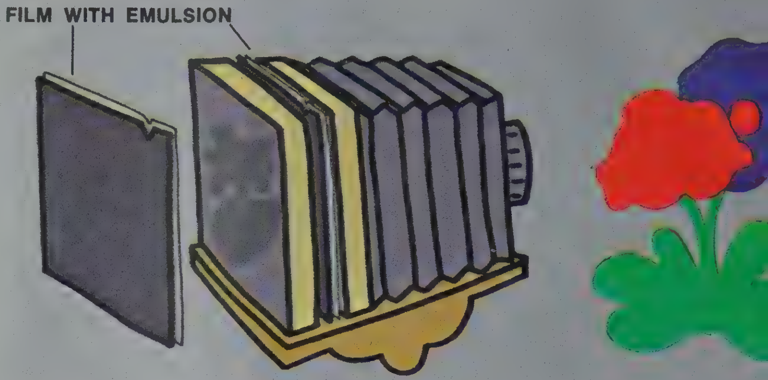
Breakfast-cereal boxes, magazines, outdoor advertising, newspapers, and this book—all of these use color photographs. The basic ideas of color filters and paint mixing are used to make and to print these photographs. Before getting into color photography and printing, though, it is important to understand how black-and-white photographs are made and printed.

A special property of light is involved. Because of this property, light fades colored cloth and turns newspaper pages yellow. Because of this property, light can also change many chemicals. In particular, a class of white solids, called silver halides, turns gray when light hits them even for a fraction of a second. This reaction makes photography and printing possible.

Photography

Black-and-white film is a strip of transparent plastic with a thin coating of silver halides on one side. This coating is called the *emulsion*.

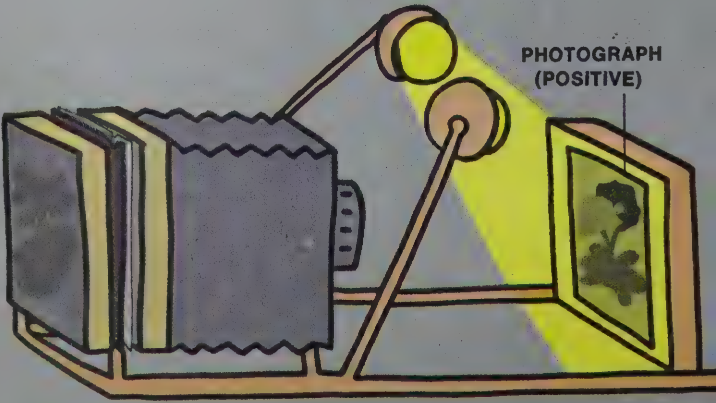
When the light from outside the camera passes through the lens, it strikes the film at the back of the camera. The light reaching the film causes a chemical change within the halides.



Printing

To print a drawing or a photograph, a printer needs a copy of it on a metal printing *plate*. The metal plate has a special coating which makes it sensitive to light the same way undeveloped photographic film is sensitive to light.

First, the original photograph or drawing is photographed with ordinary film to give a black-and-white negative. This ordinary negative is then used to make the positive on another light-sensitive film.



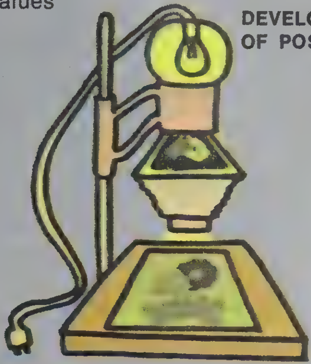
When the film is developed, these exposed silver halides turn various shades of gray. Parts of the film which received light from bright objects turn a very dark gray. Parts of the film receiving light from not-so-bright objects turn a lighter gray.

The total picture gotten from this step in developing the film is called a *negative.* The light and dark values of the objects in a negative are reversed from the way they really appear. These must be reversed again to give the actual light-dark values of the photographed scene.

So light is beamed through the negative onto a sheet of paper which has a layer of silver halides.

More light passes through the lighter parts of the negative than through the darker parts of the negative. Therefore, wherever the negative is dark, the developed print remains light. This print, called a *positive,* is the snapshot or photograph you are used to seeing.

DEVELOPMENT OF NEGATIVE


DEVELOPMENT OF POSITIVE

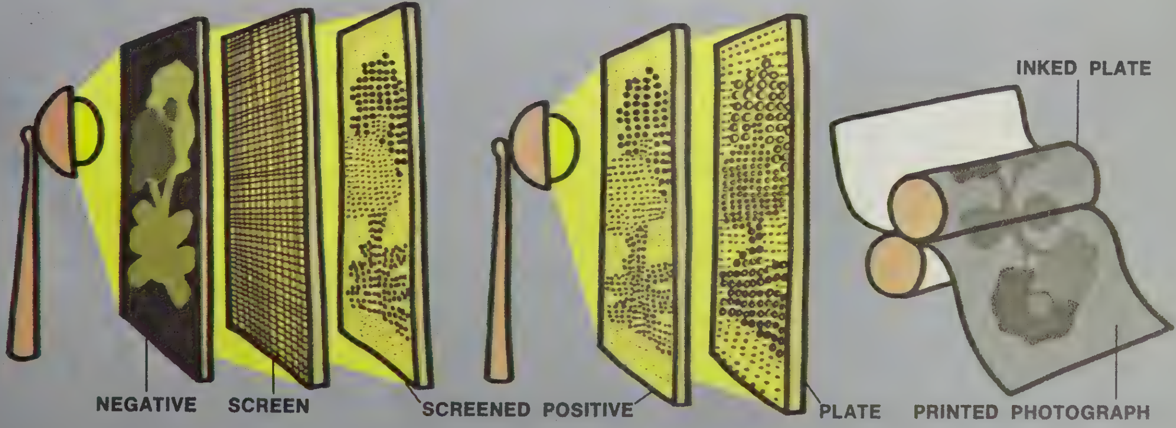
PHOTOGRAPH (POSITIVE)

A sheet of glass or plastic with many fine horizontal and vertical lines is put between the negative and the film on which the positive image is being developed. This sheet of ruled glass or plastic is called a *screen.*

Light passes through the negative and the openings in the screen. As a result, the positive film is made up of many black dots of different sizes. Where the original picture was dark, the screen makes the dots on the positive film come out large and closely packed. Where the original picture was light, the dots come out small and far apart. Such a piece of film is called a *screened positive.*

The exact pattern of dots on the screened positive is transferred photographically to the metal plate. The plate has been prepared so that ink sticks only in the dots and not anywhere else.

In the printing press, the ink is transferred from the plate to the paper so that a pattern of black dots appears. When you look at such a pattern of dots on a printed page, your brain interprets each area as a shade of gray, according to the size and closeness of the black dots. Together, these shades of gray make up a picture.



Color Photography and Printing

Examine the dot pattern in this photograph with a magnifying lens.

Film for color photography has *three* very thin layers of silver halides instead of one. That is, there are three emulsion layers. These layers are so thin that they can not be seen without a microscope.

Each layer is specially treated to be sensitive to only one of the three basic colors of the spectrum—red, green, and blue. After the film is developed, you get the colors of the original photographed scene because these three layers act as a combination of colored filters.

To print the photograph, printers apply the rules of paint mixing. They usually use the three basic colors of paint—magenta, cyan, and yellow—to produce all the other colors. To control the shades of color, they add black.

Photography

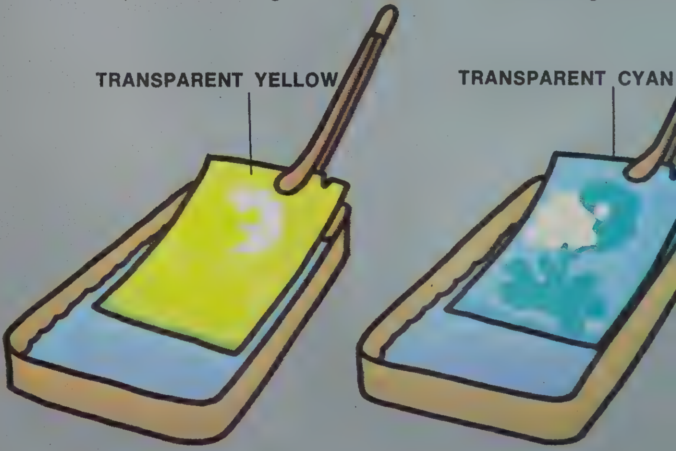
The blue-sensitive layer changes chemically in areas where ligh
containing any blue strikes. The red-sensitive layer responds t
red light. And the green-sensitive layer responds to any traces o
green light.

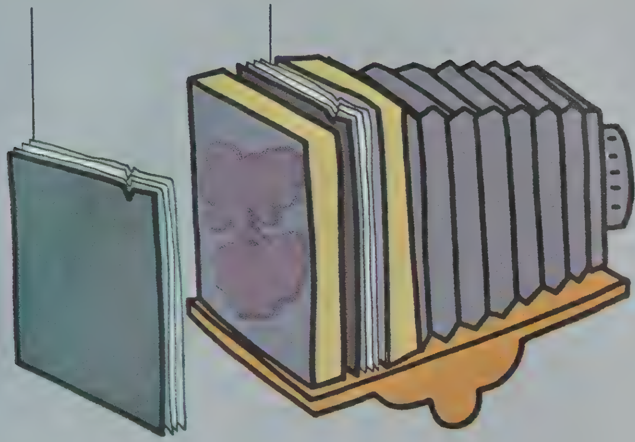
When the camera is clicked, the color film gets a pattern of chemically changed areas in each of the three layers. But each layer ha
a different pattern of these chemically changed areas.

The first step in developing color film gives color to each of th
three layers. The layer that reacted to blue light becomes yellow
The layer changed by red light becomes cyan. And the laye
changed by green light becomes magenta.

These layers on the film are not uniformly colored. The brightes
yellow areas represent those areas in the original scene that ha
the least blue. The least yellow areas represent those spots in th
photographed scene that have the most blue.

The brightest cyan areas represent those areas in the photographe
scene that had the least red. And the brightest magenta areas represent those spots in the original scene that had the least green.

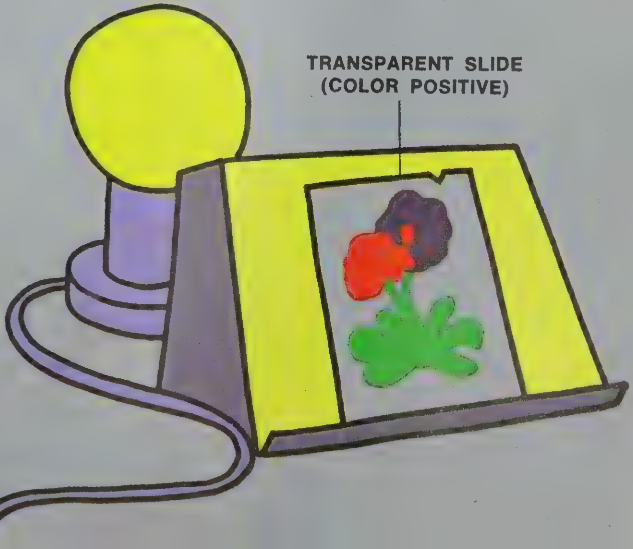



FILM WITH THREE LAYERS OF EMULSION

Since the transparent yellow, cyan, and magenta layers are on top of each other, they act as a combination of filters to reproduce the original scene.

The color positive that you get from this process is a slide. Small cardboard-mounted slides are usually shown on a wall or a screen with a slide projector. Larger ones, such as the one shown here, can be viewed on a light box. Either kind of slide can also be used to make color photographs.

There is a more complicated process for making color photographs which hasn't been discussed here. In this other process a different kind of color film is used. Negatives are made first. Then the negatives are turned into positive images on photographic paper.



Printing

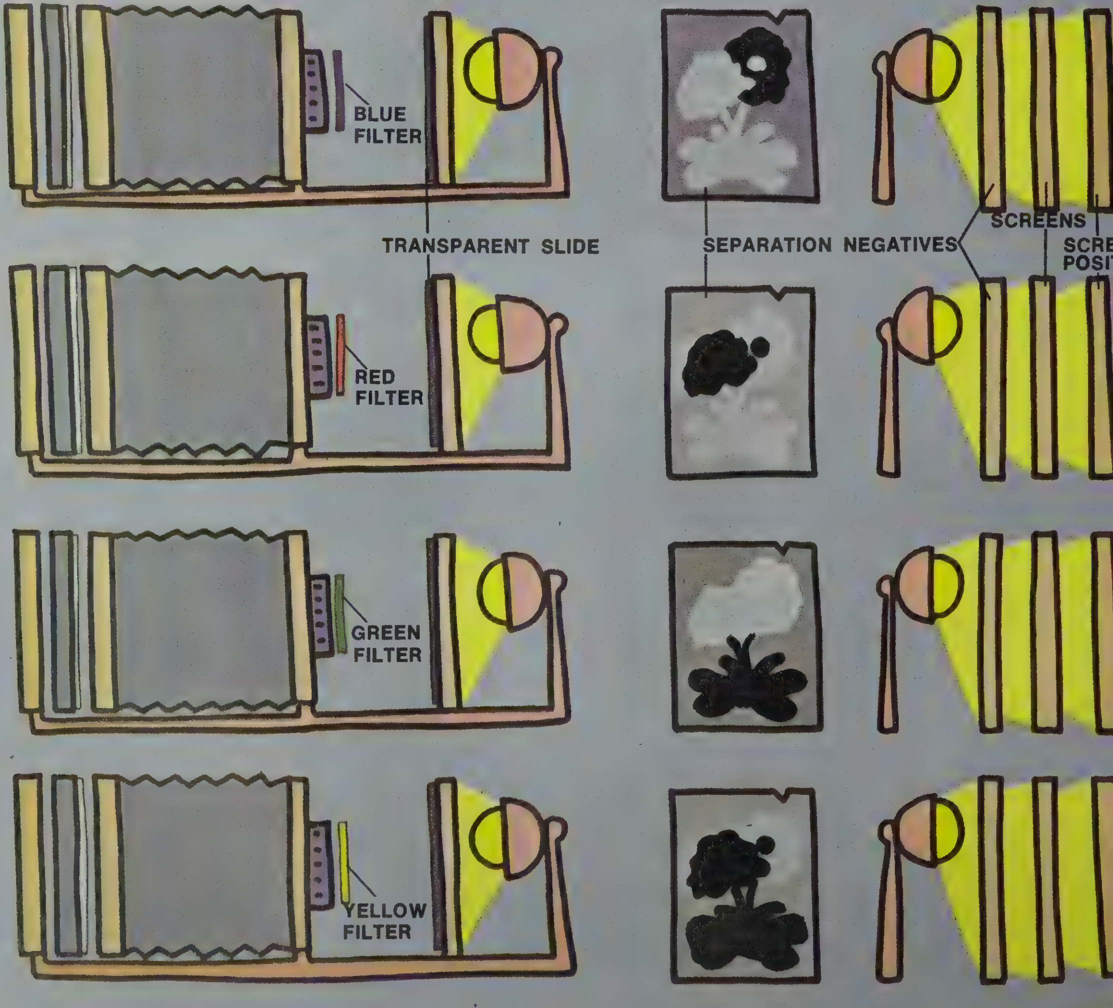
The negatives—The color drawing or photograph to be printed is photographed four times. One negative is made with a blue filter. The second, with a red filter. The third, with a green filter. And the fourth, with a yellow filter.

Each filter passes only light of its own color. Only blue light goes through the blue filter. So the first negative has black and shades of gray where blue light struck. It is completely transparent everywhere else. The red light makes a pattern on the second negative. The green light makes a pattern on the third negative. These also are completely transparent where no light caused darkening of the film. On the fourth negative, made with a yellow filter, the yellow, green, and red parts of the light make more of an impression.

The four negatives gotten this way are called *separation negatives*.

The positives—Each color separation negative is placed on a screen similar to the screens used in black-and-white printing. Light-sensitive film is placed under the screen. White light is beamed through the negative and screen, onto the film. This process creates a *screened positive*.

Let's look at the first separation negative, made with the blue filter, as an example. This separation negative is a piece of transparent film on which the blue values in the original picture appear as black or shades of gray. If you lifted up this piece of film to look through it, you would see that light is completely or partly blocked by



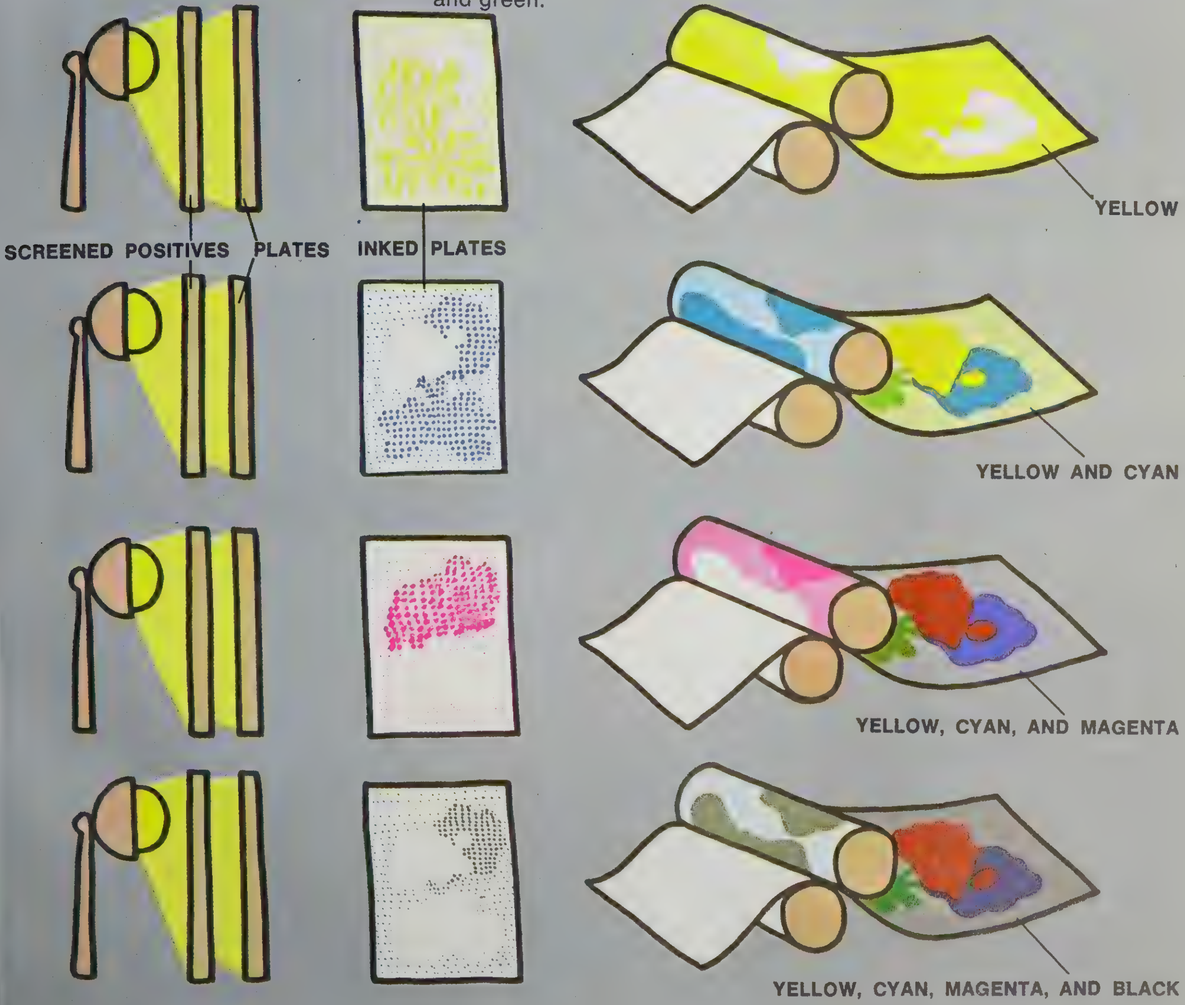
these darkened areas. The darker each area, the less light it lets through. But light passes through the clear areas of the negative easily. These clear areas on the negative represent all areas not containing blue in the original picture.

After the beam of light has passed through the screen and the negative, it strikes another piece of film and causes a change in the light-sensitive coating. Because of the screen, the light hits this second piece of film in a pattern of dots. The dots are of various sizes and closeness. The dots represent all light from the original picture that had little or no blue in it. This pattern of dots is transferred to one printer's metal plate.

A second printing plate is produced in the same way from the separation negative made with a red filter. Except in this plate, all areas containing little or no red are represented as a pattern of dots. The third printing plate has dots representing all areas containing little or no green. The fourth plate represents all areas containing little or no yellow, red, and green.

The printed copy—The printer inks the plate made with the blue filter, with yellow ink; the one made with the red filter, with cyan ink; and the one made with the green filter, with magenta ink. The ink sticks to the dots on each plate.

When the three colors of inked plates are printed one over the other, the original photograph is reproduced. To add sharpness to such printed color pictures, printers use the fourth plate, which is inked black. The result is a good printed copy of the original.



Mixing lights

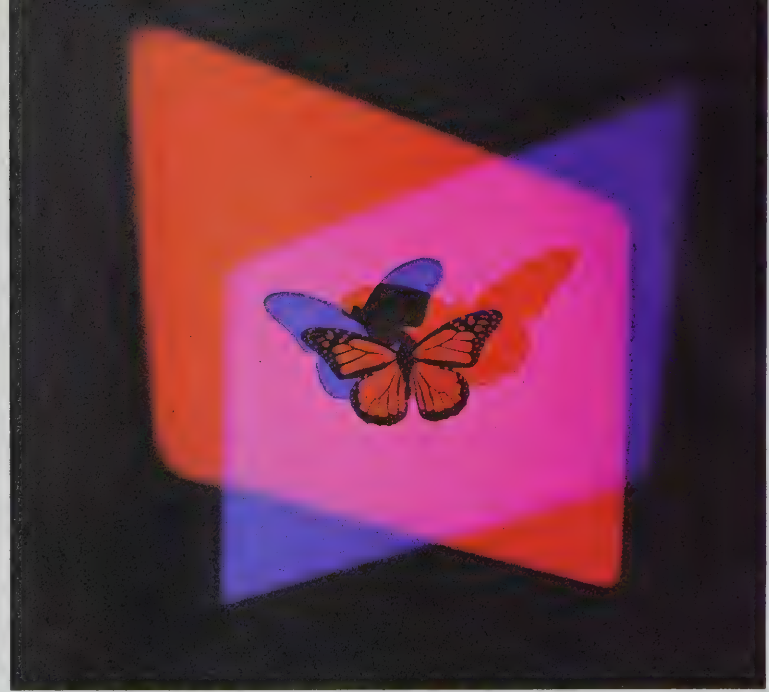
Imagine the music blasting, your friends all there, and the colored lights flashing and moving across the room to the beat of the music. Color can be as loud to your senses as music. Somehow you don't just see it—you can feel it.

Colored spotlights often are used for dramatic effect. Dancers, ice skaters, and other performers often work under them. Christmas trees and store displays are also sometimes lit by them.

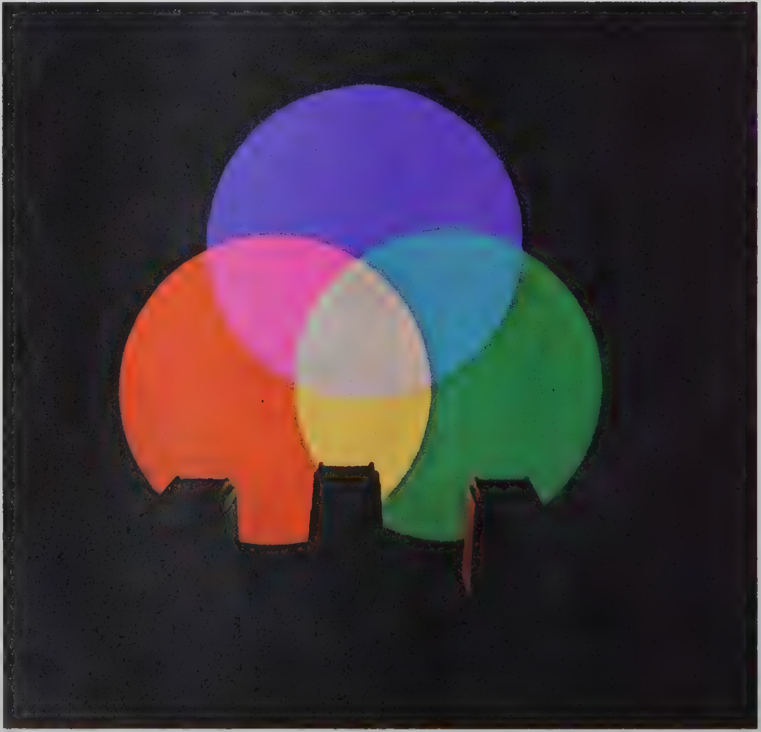
The next time you see colored spotlights used, notice what the lights do to each other when they overlap. "New-color-from-old" is one of the most interesting effects of colored lights.

Figure 1·11 shows the results you would get with fairly pure color filters in front of some white-light sources. As you know, good filters will let through just their own colors from a white light source.

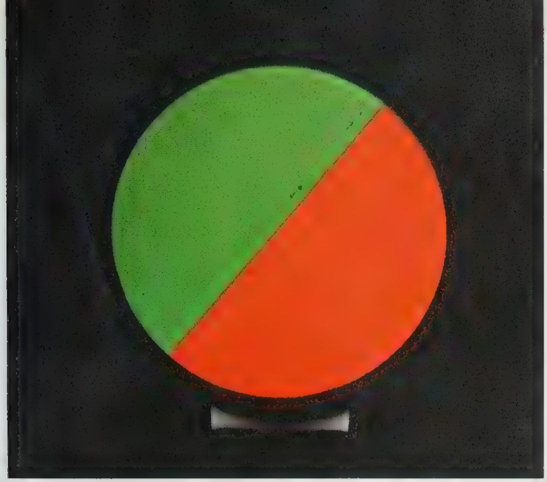
In the section where the red and green beams overlap, for instance, there is very little color being reflected other than red and green. But you see yellow! In the area where the red and blue beams overlap, you see a red-blue—



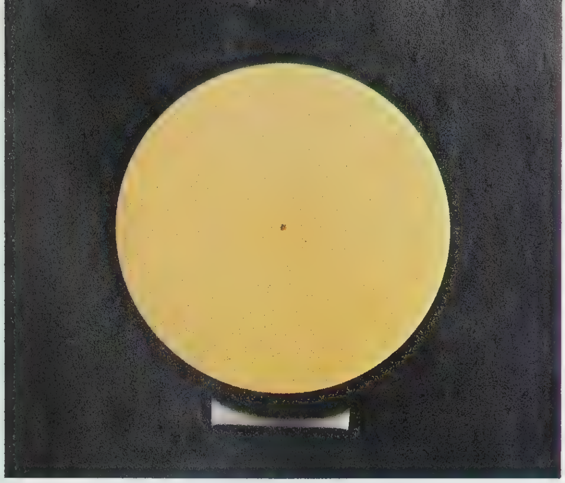
1·10 Red and blue spotlights overlapping. Notice the colors of the shadows.



1·11



1·12a



1·12b

or magenta. And where the green and blue light beams overlap you see blue-green —or cyan.

Remember that magenta and cyan are not colors in the spectrum. They are mixtures of colors your eyes see as a single color. The yellow that you see when red and green lights are mixed is also a "mix" interpreted by your brain as one color, though yellow is also a color in the "real" spectrum.

You can also see these mixtures of colored light by watching a colored disk like the one in figure 1·12. Notice that the disk is half red and half green. When the disk is spinning, the colors blur. Your eyes interpret the mixture of the light coming from both the red and the green halves. What color does the spinning disk appear to be?

You can get similar results with other colors on the disk. For instance, by spinning a disk half red and half blue, you can see magenta. By spinning green and blue, you see cyan. And by spinning a disk with red, green, and blue in equal parts, the disk should appear nearly white.

Notice that you also see a whitish spot when red, green, and blue light beams overlap (figure 1·11). Ideally, by carefully varying the brightness of these three basic colors of light, you could create any color visible to the eye. Seeing color has to do not only with the light your eyes receive, but also with how your brain interprets that light.

TEST YOURSELF

1. *What color will you see in the following cases:*
   a) when a pure green beam overlaps a pure blue beam of light on a white surface?
   b) when a pure green beam overlaps a pure red beam on a white surface?
   c) when a pure blue beam overlaps a pure red beam on a white surface?
2. *What color will you see when pure red, green, and blue beams overlap on a white surface?*
3. *What would you see if you mixed a blue beam and a red beam on a blue opaque surface? Why?*

Seeing Red . . .

For centuries, scientists have been interested in how we see color. Newton thought that every color in nature had a corresponding color receiver, or receptor, in the eye. For more than a hundred years no one offered any other ideas. But in 1801 another English physicist, Thomas Young, suggested a new theory. He reasoned that there could not possibly be as many receptors in every part of the retina as there are colors. (The retina is the back of the eye, which receives the light signals.)

Young suggested that there are only three kinds of receptors. Each kind is sensitive to one of the three basic colors of the spectrum—red, green, and blue. When more than one kind of receptor is set off, a person sees other colors—yellow, blue-green, white, or whatever color results from mixing the three basic colors.

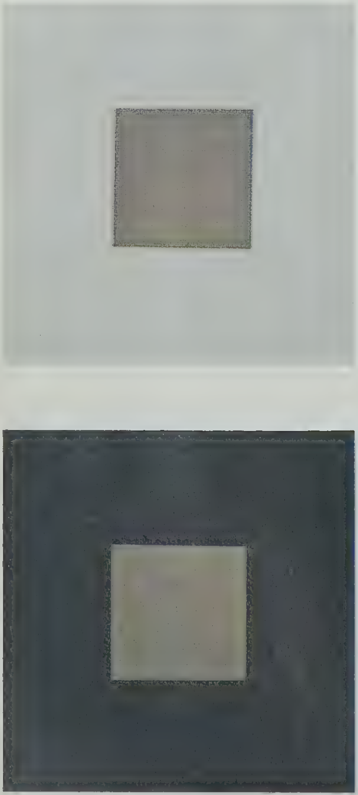
Scientists rejected or ignored Young's theory for about fifty years. Then a German physician, Hermann von Helmholtz, suggested some changes in it.

Helmholtz believed that all colors affect all three kinds of receptors, though not to the same extent. For example, if pure red light shines on your eye, the receptors most sensitive to red are strongly stimulated. The other two kinds of receptors are weakly stimulated. If pure yellow light shines on your eye, both the red-sensitive and the green-sensitive receptors are stimulated strongly. The blue-sensitive ones are stimulated weakly. You then see yellow because the sensation of yellow is the combination of red and green.

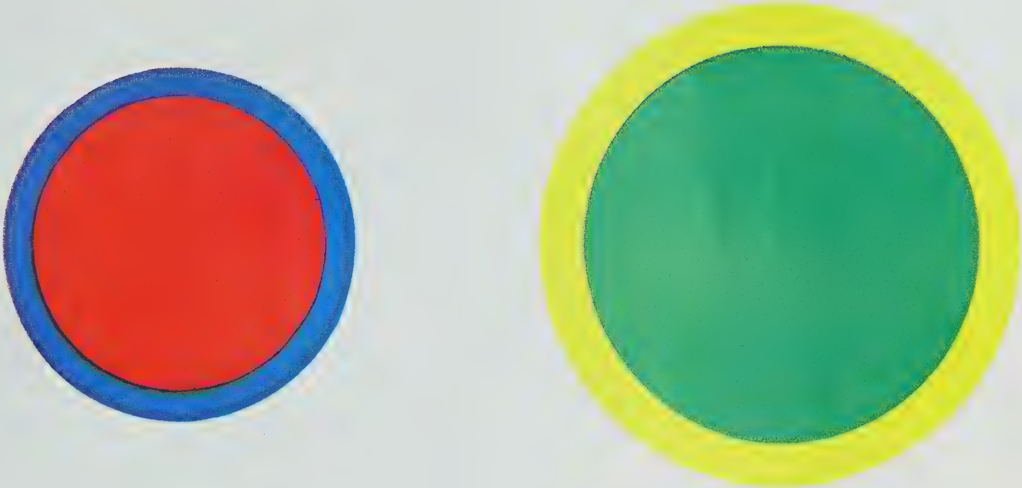
Helmholtz' addition to Young's three-color theory renewed interest in it. It became known as the Young-Helmholtz theory.

The Young-Helmholtz theory is still the basis for nearly all descriptions of color vision. But it has been altered in many ways. For instance, in 1872 another German, Ewald Hering, noticed some things which the Young-Helmholtz theory did not explain.

Look at the two gray squares in figure 1·13. Do they look like the same shade? They are, though the one against the light background appears darker than the one against the black background.



1·13



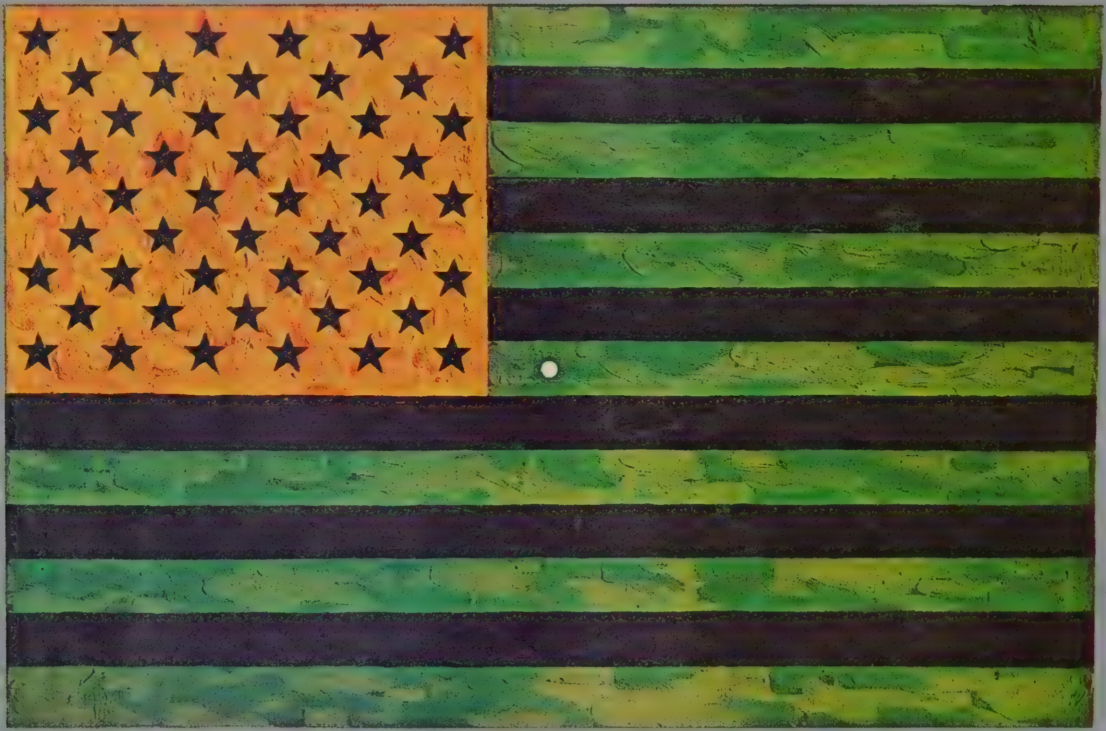
1·14

Or look at the green circle with the yellow border for about 30 seconds (figure 1·14). Keep the other circle covered. Then quickly look at a white sheet of paper or close your eyes gently. Did you still see colors? What were they? Try the same thing with the bright red circle with the blue border.

Hering reasoned from experiences like the ones above that the eye's color receptors are sensitive to *pairs* of colors. He thought that one kind of receptor must be sensitive to red and green, another to blue and yellow, and the third to black and white. For instance, when the red-green receptors become overtired with red light, the receptors become less sensitive to red. When such red-tired receptors are no longer stimulated by a color containing red, thought Hering, these same receptors have a tendency to send "green" signals to the brain.

In this century scientists have found evidence which seems to clear up the conflict between the Young-Helmholtz theory and the Hering theory.

1·15 Stare at the spot in the center of the flag for one minute. Then quickly look at a white sheet of paper or close your eyes. What colors do you see?



Modern scientists have measured the absorption of light by substances taken from color receptors from the eyes of monkeys and humans. They found evidence for only three different color-sensitive substances. Each of these substances is strongly sensitive to only one of the basic color areas of the spectrum—red, green, or blue. You see other colors when combinations of these three different receptors receive signals.

None of the color receptors works in very dim light. Scientists have identified a different kind of receptor which works only in very dim light. This kind of receptor is sensitive only to white, gray, and black.

The black-white receptors, called *rods,* contain a substance called visual purple. When no light hits the back of the eye, the supply of this substance builds up in the rods. (One of the things the rods need to form visual purple is vitamin A.) When light falls on the visual purple, it is bleached. The bleaching process sends messages to the brain. The messages can be strong or weak—depending on the amount of the visual purple which is bleached. These messages are our vision in dim or night light.

In bright light, the supply of visual purple is quickly used up. Since the rods cannot produce more visual purple in the light, they become inactive in bright light. But more visual purple is again produced as soon as only dim light enters the eyes.

The color receptors, called *cones,* work in a more complicated way than the rods. All three kinds of cones—the red, blue, and green—must usually work together. The brain must interpret the different combinations of messages. For example, you see yellow when both the red and green cones are stimulated equally. A fairly pure yellow light will stimulate the red and green cones equally. But red and green light reflecting from the same surface will also stimulate the red and green cones. So you can see yellow without any yellow light being present.

Other times, as in Hering's experiments, you can "see" colors when no colored light is striking the cones at all. The cones and nerve cells in the eye can send misleading messages to the brain. The next section is about another example of this happening.

Seeing colors when you would expect to see white light: Edwin H. Land's experiment

Now You See It Now You Don't

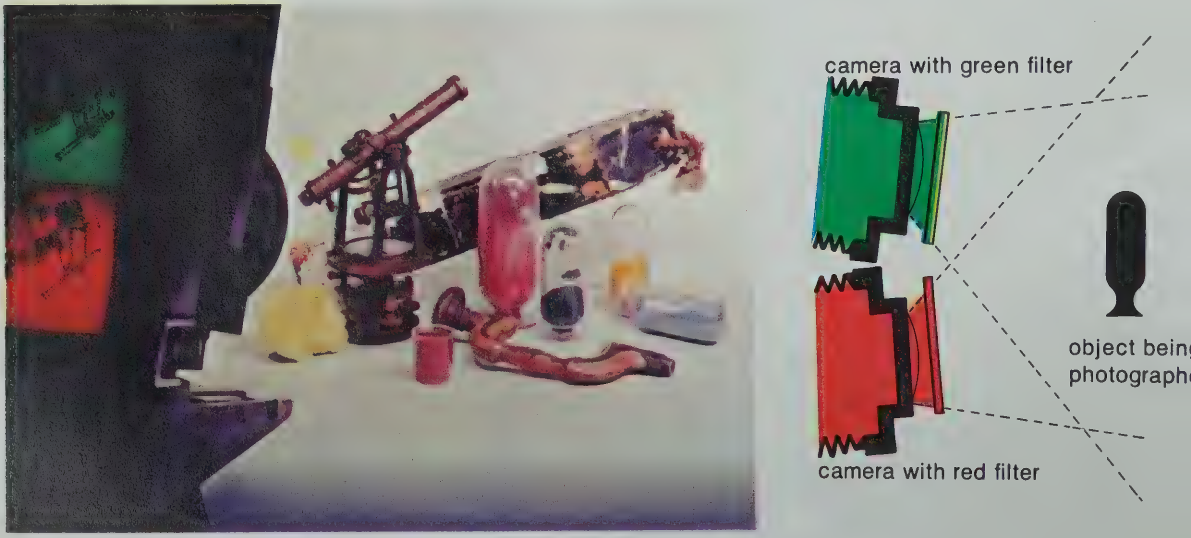
In a famous experiment with color, two slide projectors cast black-and-white slides of the same scene onto a white surface. One slide projector has a red filter in front of it to produce a pure red beam. The other has no filter in front of it. So it produces a white beam.

The images from the two projectors overlap exactly. So you would expect to see the photographed scene in various shades of pink. But you do not! You see almost *all* the colors of the original photographed scene. And only black-and-white film was in the camera when the slides were taken.

There is one little catch. The film was not exposed to white light. A red filter was in front of the camera for the slide that is in the projector with the red filter. And a green filter was in front of the camera for the slide in the projector with no filter. So the slides are not exactly alike. In each case, different colors of light were blocked before they could reach the film in the camera.

In the projectors you have a red beam, a white beam, and black-and-white slides. All the black-and-white slides can do is let through different intensities of red light or white light from the projectors.

1·16 The scene is being photographed with a double camera. It takes two photos at a time, one with each lens. A red filter is in front of one lens. A green filter is in front of the other. Black-and-white slide film is in the camera.

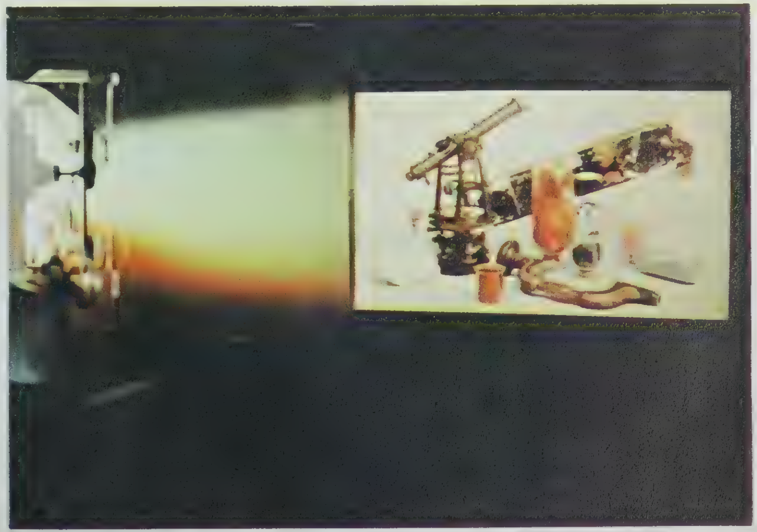


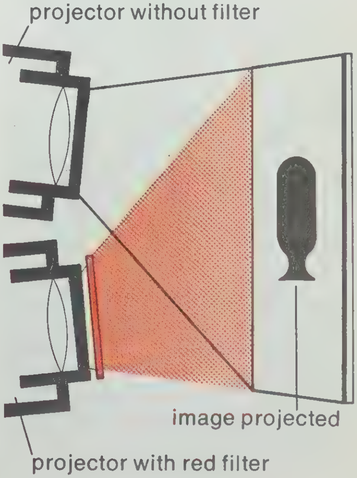
Edwin H. Land, an American scientist-businessman-inventor who worked on this experiment, was fascinated. (By the way, he is the same man who invented the Polaroid camera.) He found that we can create our own colors for almost any combination of colored projector beams and black-and-white slides taken through color filters.

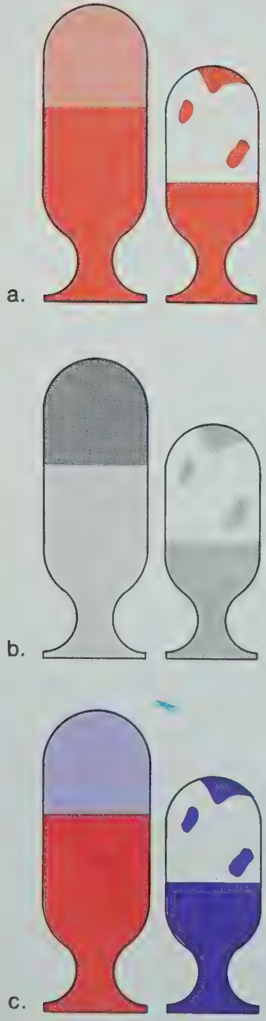
Only a few simple rules must be used. You must take two pictures of the same scene with black-and-white film. Each time you must put a different color filter in front of the camera. The band of color passed by one filter must be different from the one passed by the other. Then you must make positive black-and-white slides from the film.

You must project the slides onto a screen from two different projectors. The slide images must overlap exactly. And the colors of the projector lights should be different from each other. The colors may be the same as those of the filters used to make the slides. Or one may be colored and the other white. However, the projector with the light closest to red in the spectrum must be used with the slide taken with the filter closest to red.

1·17 The black-and-white slide taken through the red filter is projected through a red filter. The black-and-white slide taken through a green filter is projected without a filter. The images overlap exactly, and a color picture is produced.







1·18 (a) What you see when the slide taken with the red filter is projected through a red filter, (b) what you see when the slide taken through a green filter is projected without a filter, (c) what you see when the two slides are shown on top of each other.

For example, you could have taken one slide with a red filter on the camera and the other with a green filter. You could then project the slides with yellow and blue projector lights. You would have to be careful, however, to have the slide taken with the red filter placed in the projector with the yellow light. Yellow is closer to red in the spectrum than blue.

Scientists don't know how eyes create color images in these cases. In Land's experiment the difference in brightness between areas is apparently important.

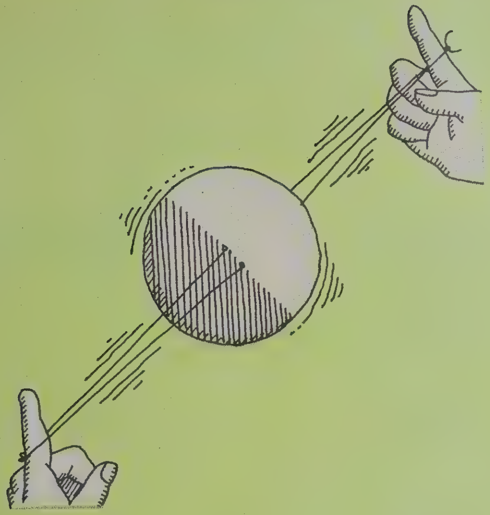
Land continued his experiment as follows: He projected just one black-and-white slide, taken with the red filter, onto a screen. He then measured the brightness of the light at many different spots. He gave the value of 100% to a spot where the black-and-white slide blocked no light. All other spots he measured in relation to it. So he had the brightness of various spots rated from 0%—no light coming from the projector—to 100%—all the light coming from the projector. He made the same kind of measurements with the second black-and-white slide, taken with the green filter.

When the two slides are shown on top of each other, many spots of the image have two sets of brightness values. For example, the slide taken with a red filter will not have let through very much blue and green light, so that black-and-white slide will be very dark in those areas of the original scene that had a lot of blue and green. On the other hand, the slide taken with the green filter will let through green readily. Thus that slide will be very light in the same areas that were dark on the slide taken with the red filter.

Land compared the color of any spot which the overlapping images seemed to have with the brightness values of that spot. He found that the color of the spot depends on both the total brightness of the spot and how much brightness each slide gives.

Land's experiments are real. They have been repeated by others many times. But what do the results mean? At the least, they tell us that the Young-Helmholtz theory of vision does not apply to all visual phenomena. That theory must be modified if the Land experiments are to be explained by it. Or we need a new theory. The inventive Dr. Land is attempting to come up with one.

ON YOUR OWN



Spinning color

You can check to see that red reflected light added to green reflected light really does give a yellowish color. Cut out a circle with a diameter of 10 centimeters (4 inches) from a piece of heavy white cardboard. Paint one half bright red; the other, bright green.

Poke two holes 1 centimeter (½ inch) apart in the center of the circle. Cut a 1-meter (1-yard) long piece of string. Put the string through the holes on the circle and tie the ends of the string together. Pull the string through the circle so that the circle is in the middle of the string as in the picture.

Now hold one end of the string around the index finger of each hand. Twirl the string and circle until the string is twisted. Then pull on the string and loosen your pull as the string twists in one direction and then the other direction. This will make the cardboard circle spin rapidly.

When the cardboard circle is spinning fast enough, your eyes should see the color formed by adding the two colors you put on the circle. If you do not have pure red and pure green on the circle, you can get some surprising results.

You can make many colors from reflected light this way. It is important what colors you put on the circle, and how large a wedge of each color you paint.

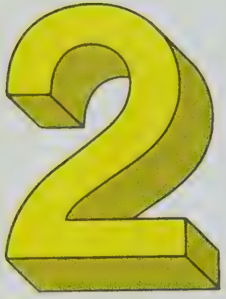
ON YOUR OWN

Changing the color in photographs

If you like photography, the following questions might interest you: What effects will you get when you use different-colored filters in front of the camera? or when you light the scene with different colors?

Make some predictions and see how they turn out.

Chapter 2: Mirror Reflections



If there were no mirrors, how would you know when the barber or hairdresser is cutting your hair wrong? Or that you have a smudge on your face? Or that you don't look so bad after all?

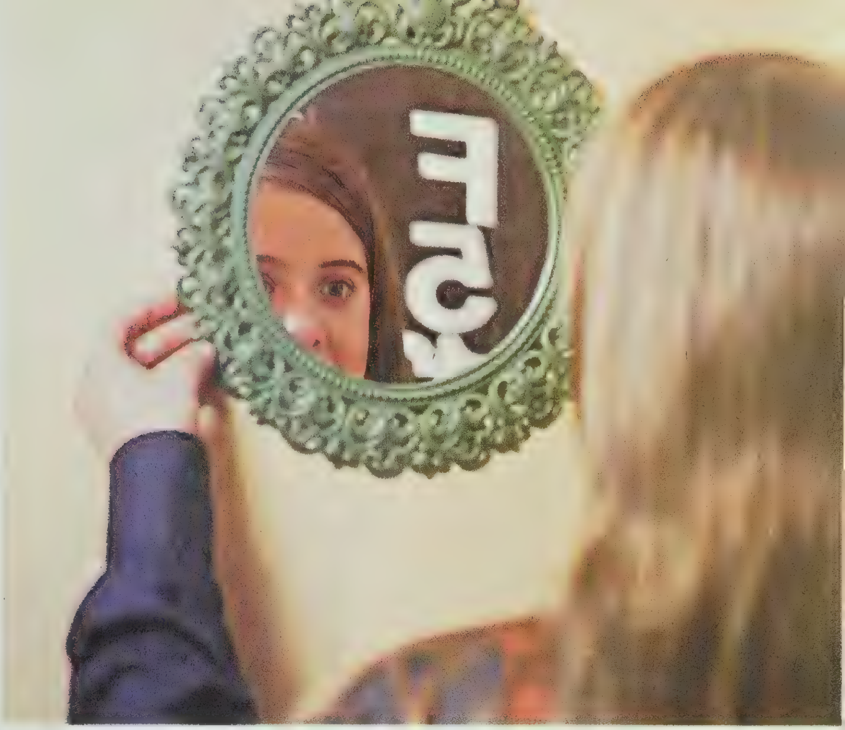
Mirrors are ordinary things, but they can be tricky. Imagine holding out your right hand to your image in a mirror. Which hand will your image offer you?

Touch your left ear with your right hand. Which hand and ear would your image use? Suppose you lie down with your right side next to a mirror. Which side of the image is next to you, its right or its left?

You can also see some interesting reflections with a curved mirror. And the mirror need not be a "real" one. It can be a shiny spoon, a bowl, or some other smooth surface.

This chapter will deal with both flat and curved mirror surfaces.

What do you see in a mirror?



2·1

You know you can't touch your mirror image though it looks like it's just behind the mirror. Your mirror self isn't really "there."

Before going any further, consider how you see something that *is* really "there." For instance, how do you see a poster on the wall?

First, remember that for you to see the poster, light must be reflected from it to your eyes.

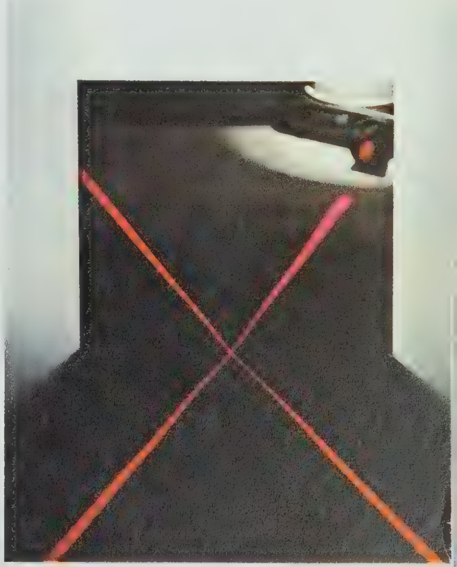
Second, no matter where you are in the room, you will see the poster if nothing is blocking your view. The poster apparently reflects light in all directions.

Third, your eyes are flooded with light rays coming from all sorts of objects from all directions. Your brain must sort the messages that come to your eyes before you can distinguish light from the poster from other reflected light.

If you turn your back to that poster on the wall, you will no longer see it. But if you hold a mirror in front and slightly to the side of you, you again see the poster behind you. The mirror somehow re-creates and sends to your eyes the scene behind you.

It re-creates the scene, but not exactly. What does the writing on the poster indicate about mirror images?

A good look at the picture with the projector light should help you recall what you might have noticed about mirrors already. The light beam produced by the projector travels along the table surface and bounces off. But you can see other light beams that seem to go right into the mirror. When you follow one of these light beams into the mirror, it leads to the image of the projector. However, in spite of appearances, the light never gets behind the mirror. It can only bounce off the surface.



2·2 Do you think the projector is on the left or the right side in front of the mirror?

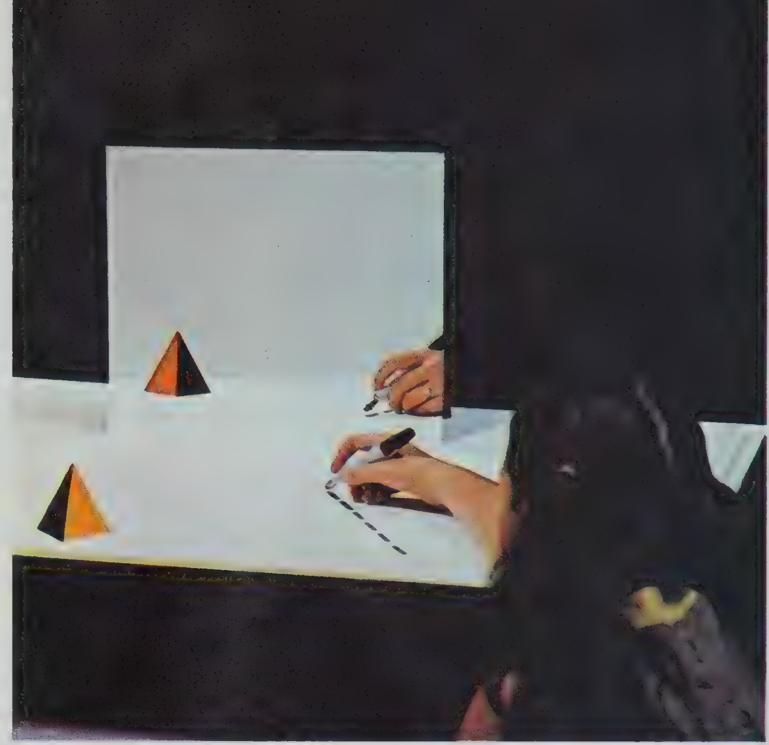
How does a mirror reflect light?

A mirror reflects light in a predictable way.

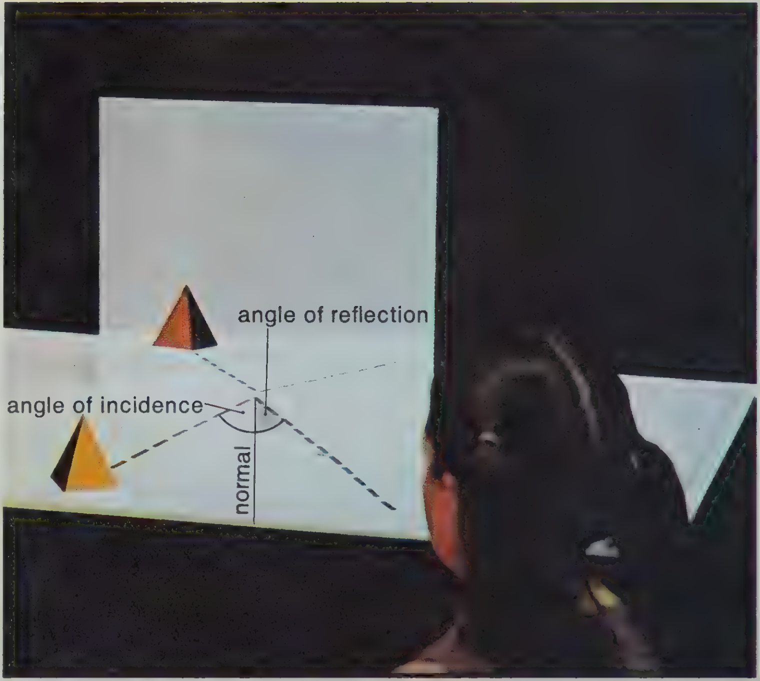
Put a small, pointed object in front of an upright mirror on a table top. Have a sheet of paper on the table top. Bend down so that your eyes are in line with the mirror. Close one eye. Look at the mirror image of the object, *not* at the object itself. With a pencil, make a dot on the paper in all spots where the pencil blocks your view of the object's image when the pencil is held upright. Look at figure 2·3 to see how this is done.

Figure 2·4 shows the pattern of marks you might get. These marks must show the path of light from the object, to the mirror, and then to your eye. They must, because you cannot see the whole object in the mirror when you move your pencil along the path of these marks.

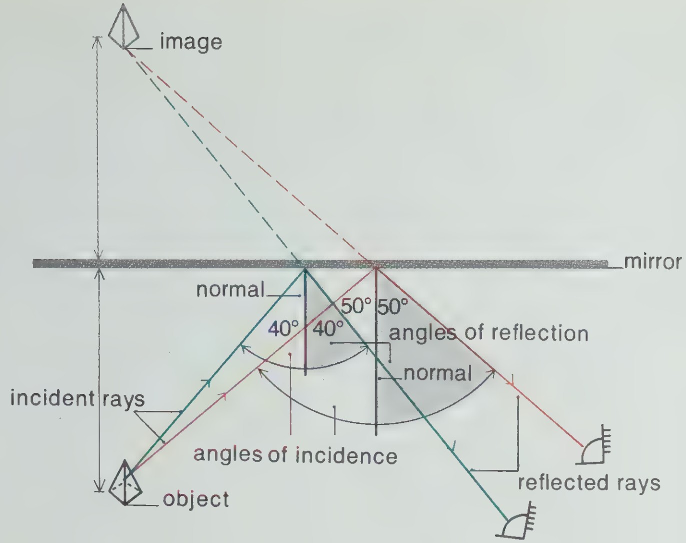
Run two more trials. In one trial, look at the object with the left eye. In the other trial, look at it with the right eye. During each trial, be sure to keep your head stationary. Figure 2·5 shows the path of light from the object, to the mirror, to your eyes when you look at the object from two such positions.



2·3



2·4

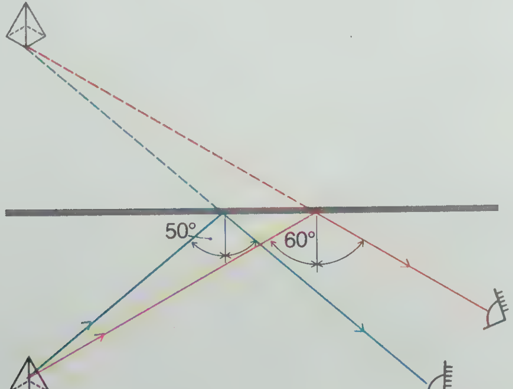


2·5

In figures 2·4 and 2·5, the line from the object to the mirror represents the path of light from the object to the mirror. In a diagram, this is called the *incident ray.*

The second line represents the light that bounces off the mirror. This is called the *reflected ray.*

Notice that in figures 2·4 and 2·5, a line has been drawn at a right angle (90°) to the mirror at the point where the incident ray turns into the reflected ray. This line is called the normal line, or just the *normal.* It's a handy line for comparing the path of the incident ray to the path of the reflected ray. Their paths are compared by measuring the angle between the normal and the incident ray and the angle between the normal and the reflected ray.



2·6

In figures 2·4 and 2·5, how does the *angle of incidence* compare with the *angle of reflection* in each case?

From this experiment and others you might have done, you can see that the angle of incidence and angle of reflection always compare with each other in this way. This rule applies to all mirror surfaces.

TEST YOURSELF

1. *Suppose your friend is sitting on a chair in the middle of the room. In what directions do you think your friend reflects light? How would you go about making observations to support your idea?*
2. *Define the term "normal" as it is used in a diagram showing a path of light which is striking a mirror.*
3. *What is the angle of reflection in each case in figure 2·6? How does the angle of reflection compare with the angle of incidence in each case?*

Newton's particle theory of light applied to reflection of light from mirrors and other less polished surfaces

What Is Light? Part 2

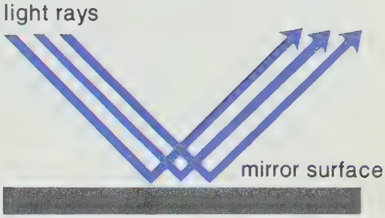
Bouncing particles

Remember that Newton thought light is made up of little invisible particles. You can use this model of light to explain why the angle of incidence equals the angle of reflection for light reflected by a mirror. When you get the chance, see if you can trace the path of a tennis ball or a handball rolled along a level surface against a wall. You can think of light as little particles which bounce from a mirror exactly as large particles (tennis balls or handballs) bounce from a wall.

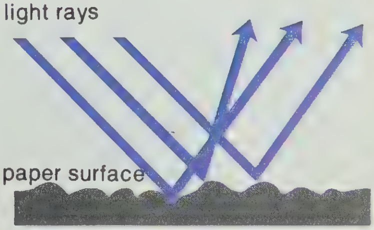
But, you might ask, why doesn't light reflected from all surfaces create images as flat mirrors do? Why is it that light reflected by a mirror from some other object carries the message of that object, while light reflected by a white sheet of paper only carries the message from that paper, no matter how many objects are around?

The important difference between a mirror and a piece of paper is in the quality of surfaces. The polished surface of a mirror is nearly perfectly flat. Light rays striking the mirror are sharply reflected at the same angle, just as a tennis ball is bounced off a flat wall. However, the surface of a flat sheet of paper, when seen under a strong microscope, is far from flat. It has peaks and hollows. Parallel light rays striking such a surface are not all reflected at the same angle. The light acts like tennis balls that are bounced off a wall of, say, unevenly rippled tin. The light is bounced off in many different directions.

For you to see a reflection of something, such as your face, all the light traveling together from your face to some surface must bounce off in the same way. If the light from your face is scattered in many directions by a reflecting surface, not enough light carrying the message of your face will reach your eyes. So instead of seeing an image of yourself, you will see only the general "message" of a plain piece of paper, which is reflecting whatever light is available.



2·7 A mirror reflecting a light beam.



2·8 A white paper surface reflecting a light beam.

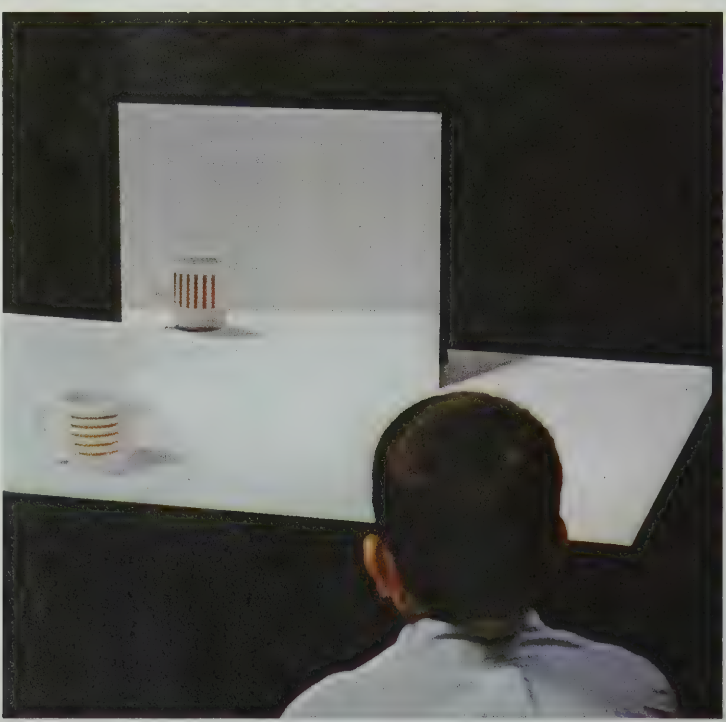
Apply the rule of reflection to a mirror image

2·9

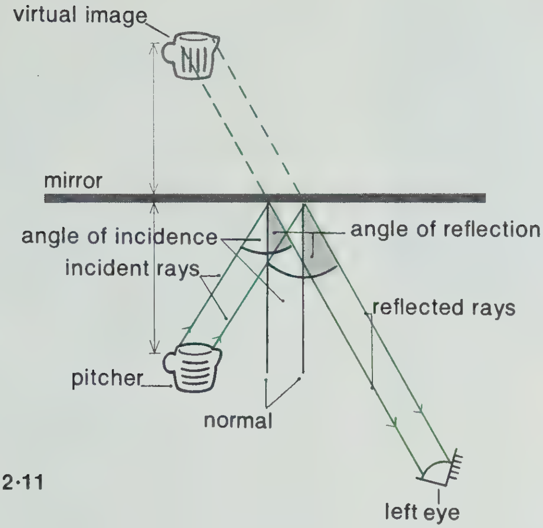
Suppose you are looking at yourself in a mirror. Every part of your face must be reflecting light *to* the mirror for you to see your whole face. The mirror in turn reflects the light back to your eyes in a predictable way. Ingoing rays of light from your face are reflected by the mirror at the same angle at which they hit. Many return to your eyes.

But is your mirror image exactly like you? Is it the same size? How far "inside" the mirror is it? Is the left side of your image the same as your own left side?

A reflection in a flat mirror is called a *virtual image*. You see it, but you can't touch it. And no matter how you twist or turn the mirror, you can't reflect the virtual image in it onto a wall or onto some other surface.



2·10



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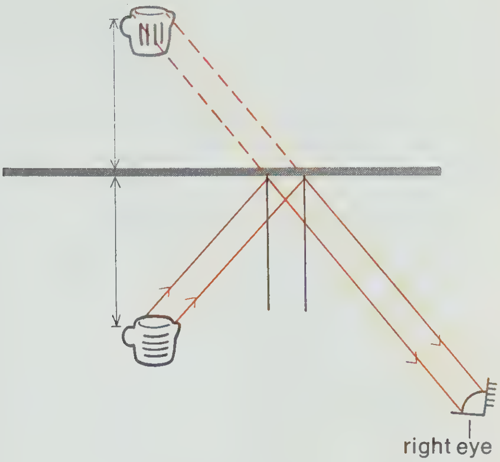


2·12

You can apply the rule of reflection to virtual images. On a diagram, you can trace the path of light rays from an object to the mirror, and then to your eyes. You can also trace the path along which your eyes seem to see the image of an object "inside" or "behind" the mirror. Such a *ray diagram* can help you understand why a mirror image seems to be the size it is, why it seems as far inside the mirror as it does, and why the left side of the image is not the same as the left side of the object itself.

Your face is a complex thing to diagram. It is easier to draw a ray diagram for a simple object, such as a small pitcher.

Notice what the front of the pitcher looks like in figure 2·9. In figure 2·10, the front of the pitcher is facing the mirror. Is there anything about the image that is different from the actual front view of the pitcher?

A person is looking at the virtual image of the pitcher in the mirror. The diagrams show parallel light rays from the spout and handle of the pitcher traveling to the mirror and then to each of the person's eyes (figures 2·11 and 2·12).

Try to answer the following questions by looking at the diagrams:

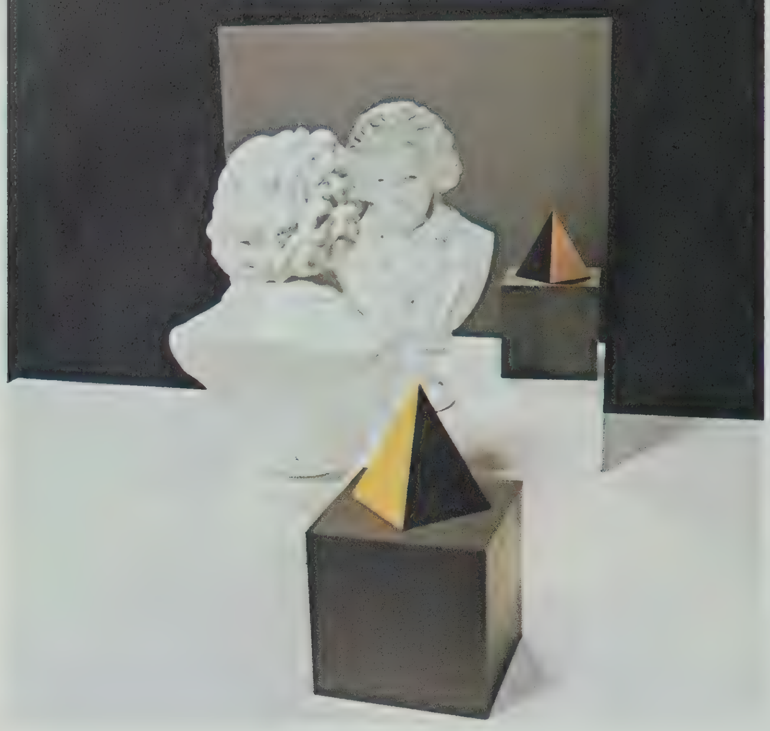
(1) Are the two parallel rays in each diagram reflected to the person's eyes at the same angle?

(2) How does the distance the image seems to be inside the mirror compare with the object's distance from the mirror?

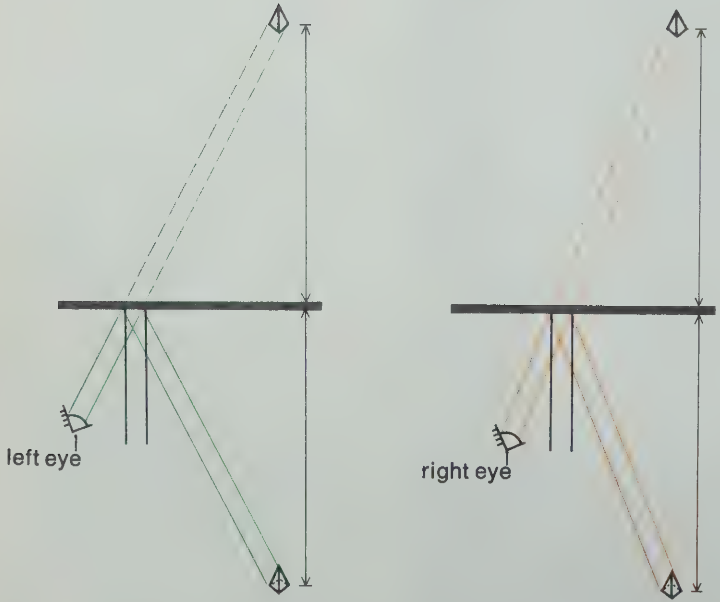
(3) How does the size of the object compare with the size of its image?

(4) Is the left side of the object the same as the left side of the image? (That is, is the spout on the image of the pitcher on the same side as it is on the pitcher?)

For the last question, also compare the photograph of the front of the pitcher (figure 2·9) with the photograph of the mirror image of its front side (figure 2·10).



2·13a



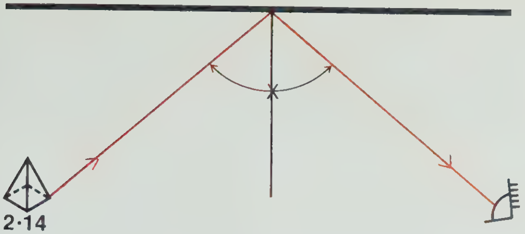
2·13b Diagrams of the view from Beethoven's left and right eyes.

To give yourself more practice in figuring out virtual images in flat mirrors, study figure 2·13b. Try to answer the four questions on the previous page with these diagrams.

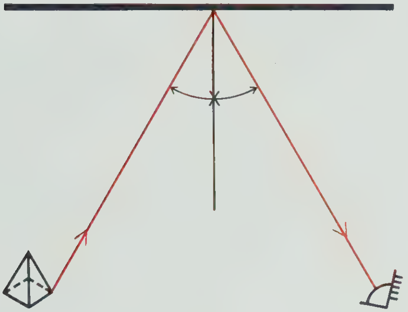
Notice that all the diagrams on these two pages show two viewing positions—first with one eye, then the other. You should observe a mirror image from more than one position to check that you really are making accurate observations about its appearance and location.

TEST YOURSELF

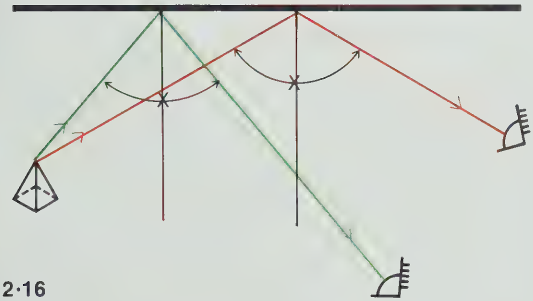
1. *This one is one for the fun of it: Can you twist your left hand so that it looks exactly like your right hand? The palms of the hands should face the same direction and the thumbs should point in the same direction. Try to create that impression with a flat mirror.*
2. *a) How large will the virtual image appear to be as compared with the object in figure 2·14?*
   b) What distance inside the mirror will it appear to be?
   c) Will the left side of the image be the same as the left side of the object? Explain.



2·14



2·15



2·16

3. *Copy the diagrams in figures 2·14, 2·15, and 2·16 on a piece of paper. Complete the diagrams to show the size and location of the virtual images.*

ON YOUR OWN

How large must the mirror be?

Suppose you wanted to buy a mirror you could use as a full-length mirror, but to save money, you wanted to get the smallest mirror that would do the job. How long a mirror would you need?

Stand in front of a tall mirror and estimate how much of the mirror you need to see your whole image. Test your prediction by blocking off sections of the mirror until you can no longer see all of yourself in it. Or figure it out using a ray diagram of yourself in the mirror. (Remember the law of reflection, and that light from your feet must reflect off the mirror to strike your eyes.)

Try to find out how long a mirror you need to see your whole image at several different distances in front of the mirror. Will the same-size mirror work no matter how close to the mirror or far from it you are?

A historical view of mirror use and manufacture

Mirror, Mirror on the Wall

Mirror images have always intrigued people. In ancient cultures mirror images were thought of as magic. Many believed a mirror reflects a person's soul as well as his or her outer appearance. From this idea follows the belief that a person can damage the soul—or have bad luck—if the person breaks a mirror. Another belief was that the devil can capture a person's soul by capturing the person's mirror image.

Mirror images have played an important part in stories too. One from ancient Greece tells about a boy named Narcissus who spent too much time looking at his image in a brook. So the gods changed him into a flower beside the brook.

A mirror image is also involved in another fable from ancient Greece. In this one, told by the storyteller Aesop, a dog is carrying a piece of meat in his mouth as he trots across a log over a stream. The dog sees his image in the water. But he doesn't recognize it as his. He wants the other dog's meat. But when he opens his mouth to grab it, he loses his food in the water.

Though both these Greek stories use water as the reflecting surface, scientists believe that metal mirrors were used in many ancient cultures. Archeologists have found bronze mirrors about 5,000 years old. They look very much like modern hand mirrors —flat round reflecting surfaces with handles.

People commonly used polished metal mirrors until well past the Middle Ages. However, by the 16th century, glass mirrors were common, especially in Venice.

The glass makers of Venice had an involved process for making mirrors. They did not know how to make flat pieces of glass directly. They started by blowing hollow tubes of glass which they cut and flattened. Next they polished the flattened pieces. Then they laid a sheet of tin foil on some other flat surface, spread clean mercury on the foil, and laid a sheet of paper over the mercury. Then, very gently, they lowered a sheet of glass onto the paper. They pulled out the paper as the glass was about to touch it. Thus the clean surface of the mercury came in contact with the glass. The Venetians left heavy weights on the glass until the excess mercury was squeezed out. At the end of the process, the back of the glass

2·17 A stone relief from ancient Egypt showing a person with a round metal mirror.

had a smooth layer of tin and mercury. This layer was the reflecting surface.

Another process of coating glass with a metal was invented in 1835 by Justus von Liebig (lē′bik), a German chemist. He used silver as the backing. He found that a form of silver will stick to glass when it is mixed and heated with a chemical called formaldehyde. Silvered mirrors are still very common today. However, modern mirror manufacturers have improved the silvering process a great deal. Now they usually spray specially prepared silver onto the back of a glass sheet. Then they spray copper onto the silver layer to protect it. Finally they apply several layers of dark paint.

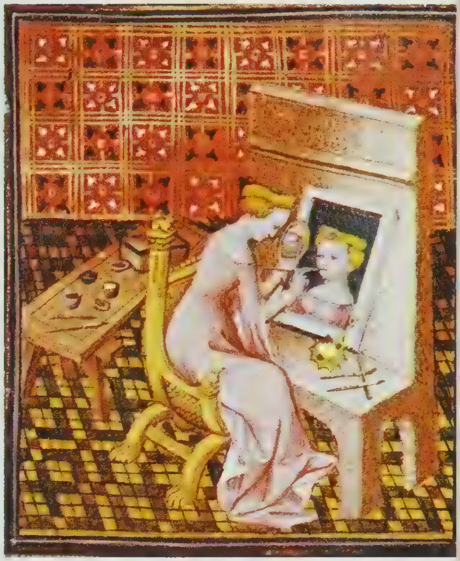
Either the front or the back of a mirror may be silvered, depending on how the mirror is to be used. Ordinary, flat mirrors are silvered on the back. In this way the silver layer is protected from being easily scratched. However, the light striking the mirror must pass through the glass to be reflected by the silver backing. The resulting mirror image will be just a little distorted. The upper surface of glass also reflects some light, which adds to the distortion.

For everyday use, small distortions in a mirror image are not important. However, mirrors used in delicate instruments, such as astronomy telescopes, must give accurate mirror images. So mirrors used in such instruments are silvered on the top surface.

Recently, a new way of making reflecting surfaces has been developed. A thin, clear sheet of plastic is covered with a very thin layer of aluminum. The thin layer of aluminum lets through some light and reflects the rest. Sometimes school laboratory mirrors are made this way.

Big, very thin sheets of such plastic can be applied to window panes on the sunny side of a building. People inside the building can see out during the day because the aluminum-coated plastic sheets let some light in. But the inside of the building stays cool because the material also reflects much of the light.

With such windows, an interesting thing happens at night when it is lighter inside than it is outside. From the outside the windows look ordinary. From the inside of the building, such windows are mirrors and reflect everything in a room.



2·18 Manuscript decoration from the Middle Ages.

You have probably looked into a make-up mirror or a shaving mirror at one time or another. Do you remember seeing an image of your face that was a little larger than life size? Getting such an image is handy when you want to see your face closely. If you examine a mirror that gives a larger-than-life-size image, you'll notice that it is curved inwardly slightly. An inwardly curved surface is called *concave.*

If you experiment a little, you can get three kinds of results when you look at yourself in a concave mirror. At one distance you can see a larger-than-life image of your face. At another distance, you can see just a blur of color. From yet another distance, you can see an upside-down image of yourself.

To see how your distance from the mirror affects what you see, let's take a closer look at how curved mirrors reflect simple light beams.

Concave mirrors, just as flat mirrors, reflect light at the same angle that light strikes the mirror. That is, the angles of reflection equal the angles of incidence. But to find these angles, you must think of concave mirrors as a series of small *flat* sections in a curved line. The light ray's angles of incidence and reflection are measured with respect to the imaginary flat section where the light ray hits the mirror.

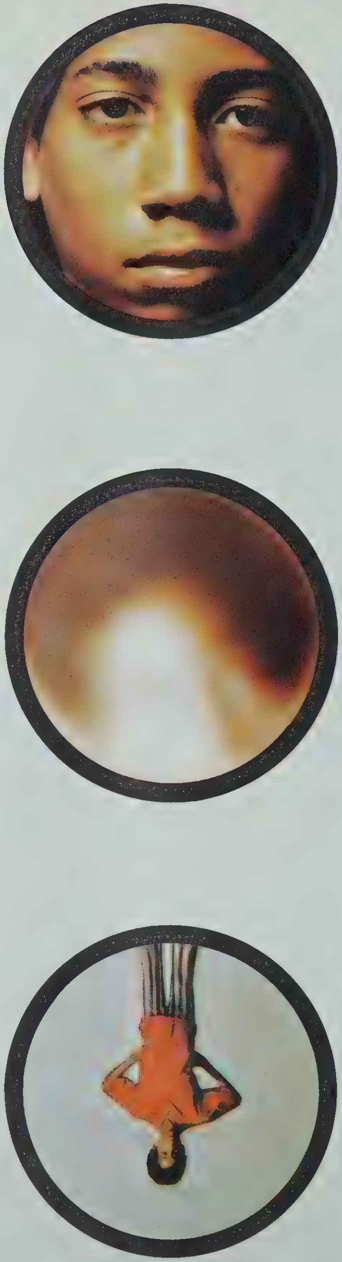
Notice how much alike the light is reflected from the mirrors in figures 2·20 and 2·21.

The point at which reflected beams cross in front of a curved mirror is called the mirror's *focal point.* However, all reflected beams do not cross at the focal point—only those which were parallel to each other when they were ingoing.

The distance from the center of the curved mirror to its focal point is called the *focal length* of that mirror.

Notice what effect the curve of a mirror has on the focal length of a mirror (figures 2·22 through 2·24). Is the focal length longer or shorter when the mirror is more curved?

The curved mirrors in figures 2·21 through 2·24 are curved in only one direction—from one side to the other—and not from top to bottom. Shaving and make-up mirrors, like the one in figure 2·19, are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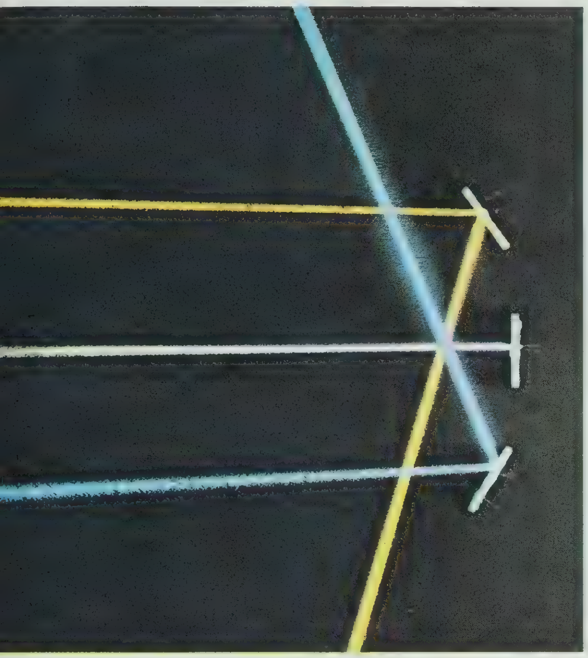

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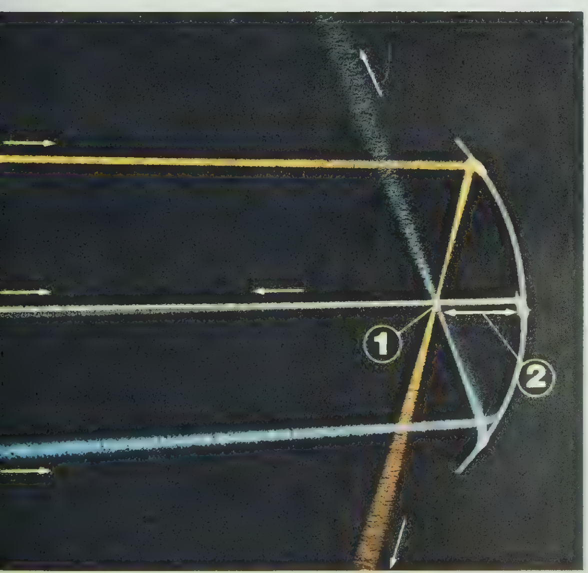
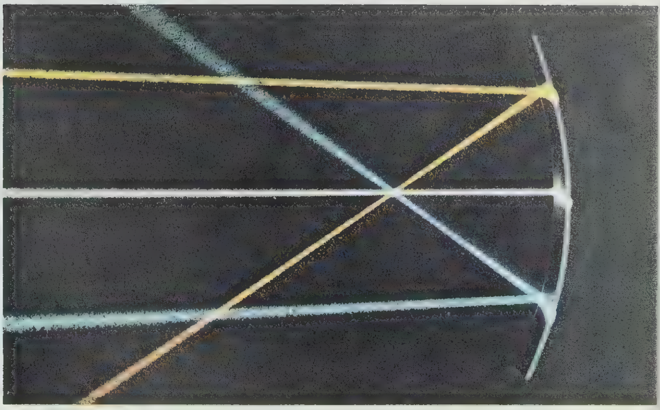


2·21 Light shining along the center line of a curved mirror is reflected back upon itself. Reflections of beams that strike the mirror parallel to its center line cross in front of the mirror at the focal point ①. The distance from its focal point to the center of the mirror is its focal length ②.



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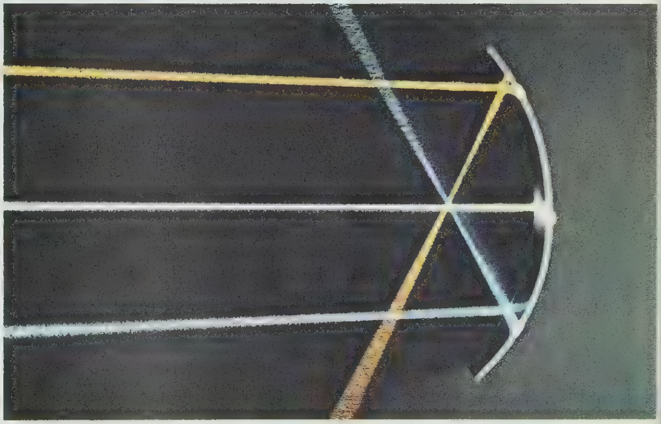

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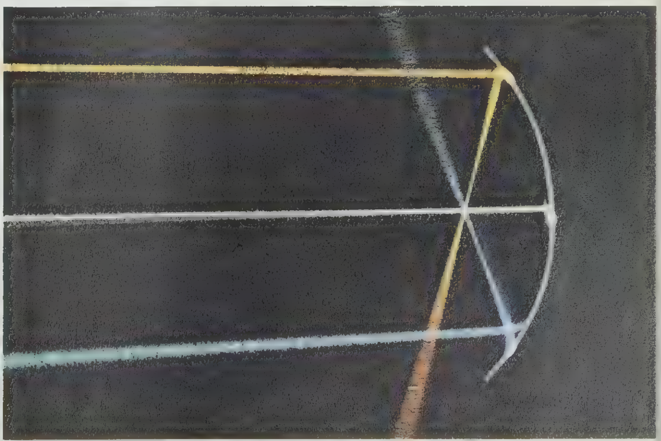

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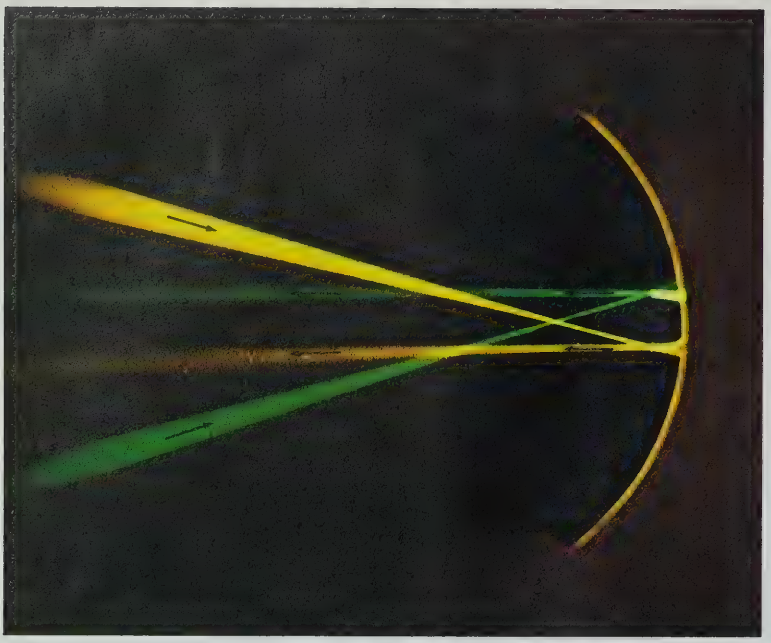


2·25

curved in all directions. However, the same rule applies to both kinds of curved mirrors. Parallel light beams striking the concave surface of either mirror will be reflected back through the focal point.

You can prove another interesting thing to yourself. If you shine light beams through the focal point, notice how the light is reflected (figure 2·25). How would you describe this property?

Keep in mind these two observations of how concave mirrors reflect simple light beams. They will help you examine the images in concave mirrors more closely.

TEST YOURSELF

1. *Define the term "concave."*
2. *Describe the three kinds of images you can see in a concave mirror.*
3. *Does the rule of light reflection apply to concave mirrors as it does to flat mirrors? Explain.*
4. *Define the term "focal point" as it applies to any concave mirror.*
5. *Define the term "focal length" as it applies to a concave mirror.*
6. *If two light beams head into a concave mirror through its focal point, how will the two beams be reflected?*

What's the larger-than-life image you see?

When you get the chance, compare your image in an ordinary flat mirror to that in a concave shaving or make-up mirror when your face is close to the mirror. You will see that your images are alike, except for one thing. Your image in the concave mirror is larger than life. The diagram in figure 2·26 shows the possible way light rays from an object might be reflected by a concave mirror so that you see an enlarged image.

Notice that the two things you have learned about the way concave mirrors reflect light are used in the diagram. Parallel light rays striking a concave mirror are reflected back through the mirror's focal point. Rays which are striking the mirror along a path which goes through the focal point are reflected parallel to each other.

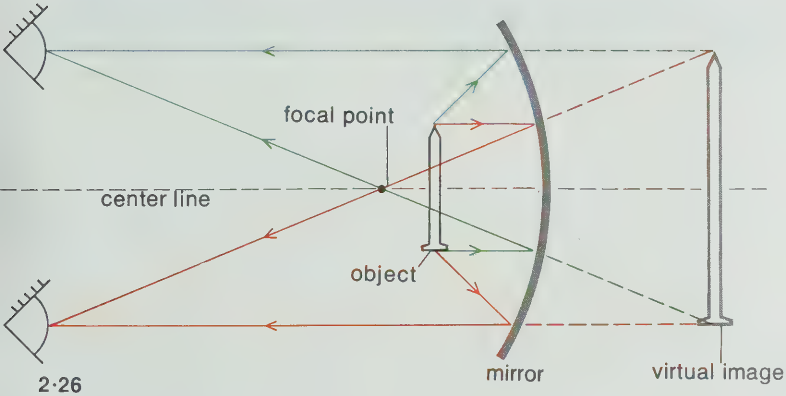
When something is between a concave mirror and its focal point, as in figure 2·26, you'll always see its virtual image. Your brain "sees" the image behind the mirror. Just as in diagrams for a flat mirror, the dotted lines behind the mirror represent your imaginary line of sight to the image.

One of the things affecting the size of a virtual image in a concave mirror is the amount of curve the mirror has. You can probably predict whether a slightly curved or a sharply curved mirror will give a larger image if you keep an object the same distance from the mirror. Compare figures 2·26 and 2·27. Do they support your prediction?

As you move an object back and forth in front of a concave mirror, there is one position of the object where you see only a blur in the mirror. If you measure from the center of the mirror to this area, you will find you have the object at or near the focal point of the mirror.

When you move an object through this blurry area and farther from the concave mirror, you will see something different—a smaller-than-life upside-down image. If you are the "object," wink with your left eye. Or extend your right hand to the image.

On which side do you think the image will wink or which hand will it extend? Try it sometime with a concave shaving or make-up mirror. (You might want to look back at the third photograph in figure 2·19.)



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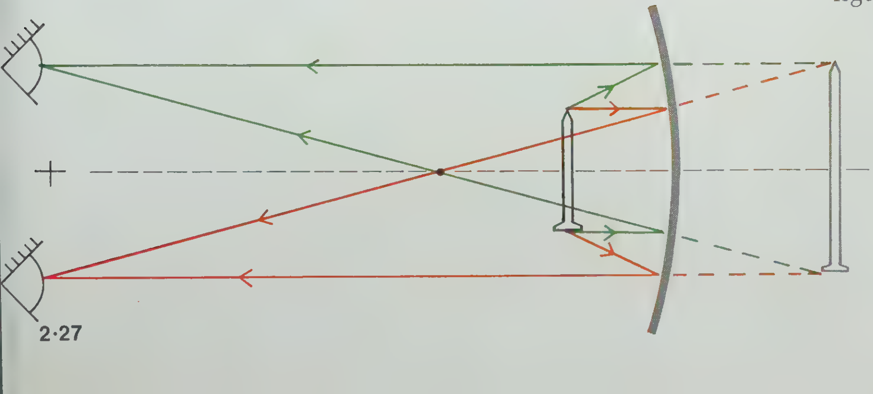

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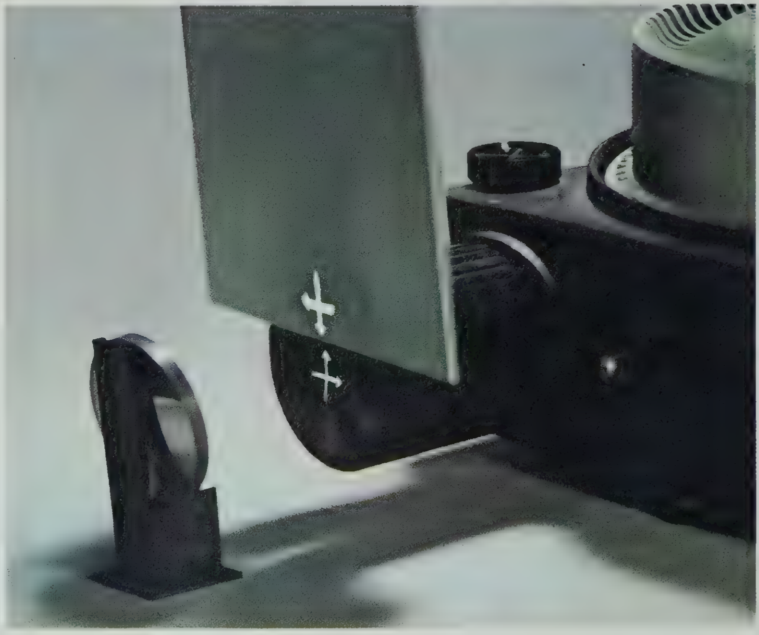


2·28 A mask with a cut-out in the shape of crossed arrows is covering the projector lens. The concave mirror is projecting an upside-down image of these arrows onto the card.

If the upside-down image created by a concave mirror is bright enough, you can do something interesting with it. You can project that image onto another surface, such as a wall or a card (figure 2·28). You can *not* project an image onto a wall or piece of paper if you use a flat mirror. Try it.

Flat mirrors give only virtual (not-there) images. Virtual images can not be reflected *onto* anything. If you want to see a virtual image, you have to look right into the mirror. And, the only way you can photograph a virtual image is to point the camera at the mirror so that the camera "sees" the same thing as your eyes would in that position.

On the other hand, you don't have to look into the mirror to see the upside-down image reflected by a concave mirror. If a card or some other surface is at the right distance in front of the mirror, the mirror can project an image onto that surface. You can then look at that surface and see the upside-down image.

These upside-down images, which can be projected onto another surface, are called *real* images.

There is a reason why flat mirrors can not reflect an image onto another surface and concave mirrors can.

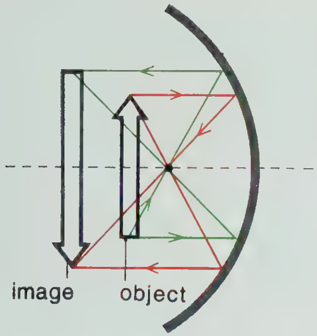
Remember that parallel light rays striking a flat mirror will all bounce off the mirror at the same angle and in the same direction. If nothing interferes, no two or more of these reflected rays will meet to form an image on another surface.

The two rules you know about the way concave mirrors reflect light can help you understand why concave mirrors *can* project real images of objects onto a surface.

1) Light rays striking a mirror parallel to each other will both be reflected and meet at the focal point of a concave mirror.
2) Light rays traveling along paths which cross the focal point will be reflected by the concave mirror parallel to each other.

In figure 2·29, study how these two rules are applied to trace the path of light rays striking the mirror from the object.

Notice where the real image is formed in each case. What two different kinds of rays meet to form the bottom of the image? to form the top of the image? How does the distance of an object from a concave mirror affect the size and location of its real image?



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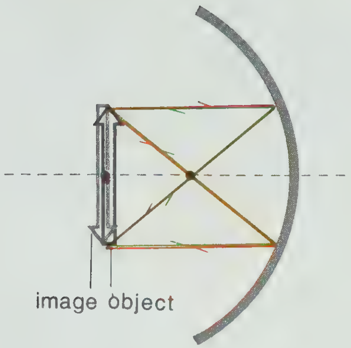

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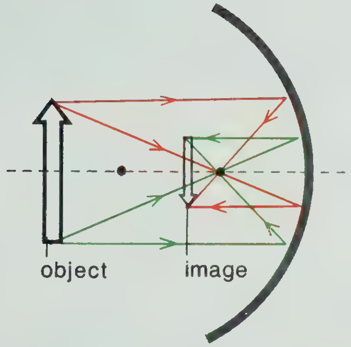

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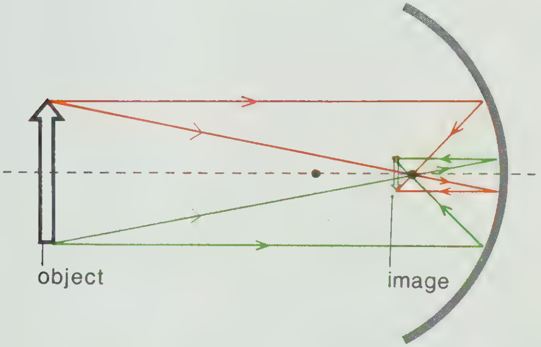


2·29d

TEST YOURSELF

1. *Which kind of image in a concave mirror can be focused onto a wall or some other surface—a virtual image or a real image?*
2. *When you put your face very close to a concave mirror (within one focal length), are you seeing a real or virtual image? Is it larger or smaller than life size?*
3. *If an object is exactly at the focal point of a concave mirror, what will the object look like in the mirror?*
4. *What are the two rules which have been used in this section to explain images in concave mirrors?*
5. *Describe how the size and location of a real image changes as an object is placed before a concave mirror (a) between one and two focal lengths, (b) at two focal lengths, (c) a little farther than two focal lengths, and (d) noticeably farther than two focal lengths.*

A concave reflecting surface is used to harness the sun's energy

Sunlight: Fuel for a Furnace

Things such as metal chairs or cars get hot if left in the sun on a warm day. You, too, get warmer sitting in the sun than in the shade on such a day. Light is associated with heat. A solar furnace is a device that uses this idea. It captures sunlight for its heat energy.

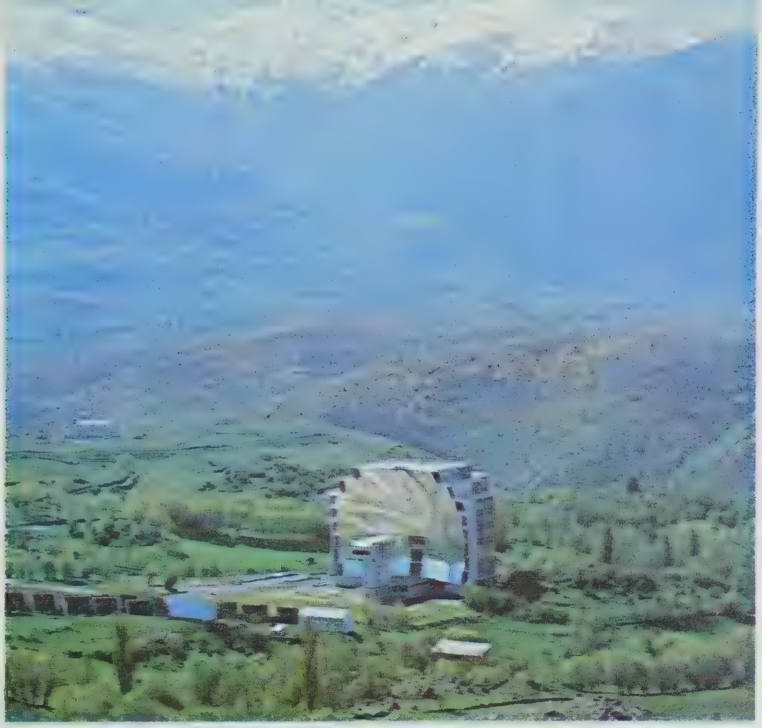
One of the world's largest solar furnaces is in Odeillo, a small village in the French Pyrenees mountains. This solar furnace has an eight-story-high concave reflecting surface which can concentrate enough sunlight to cause temperatures of over 3,300° Celsius (or about 6,000° Fahrenheit).

The huge concave reflecting surface is really made up of 8,570 separate mirrors. These many small mirrors are adjusted so that they all focus light to a point exactly 18 meters (59 feet) in front of the eight-story reflecting surface.

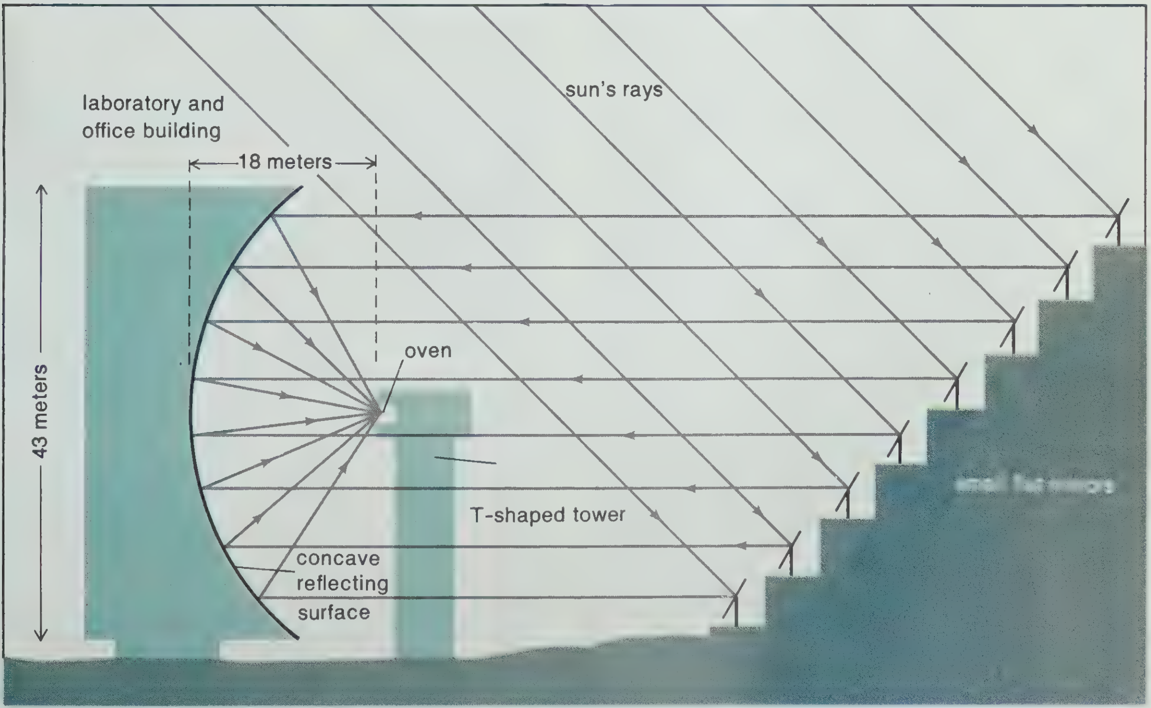
As you know, a concave reflecting surface will concentrate incoming parallel light at its focal point. The Odeillo solar furnace has a special way of getting parallel light to its concave surface. Sixty-three small mirrors are in rows on a slope opposite the concave surface. These small mirrors follow the sun as it moves across the sky. They capture its light and bounce it to the concave reflecting surface. Each of these small mirrors has a special control which automatically tilts the mirror at the correct angle to the sun and the concave reflecting surface.

The sunlight which the concave surface receives from these smaller mirrors is focused in an "oven" building. In this building, a target, such as a piece of metal, can be lifted to the focal point to test its resistance to heat. A trough under the target material carries off the material as it melts and drips from the sun's heat. For example, it takes only one minute for light reflected by the huge concave surface to cut a hole through a steel plate about 1 centimeter thick!

A very good thing about the solar furnace is that its energy output comes directly from the sun. Nothing has to be burned to obtain this energy. Thus the furnace does not add pollution to the air.



2·30 Solar furnace at Odeillo in the French Pyrenees mountains. Notice the concave reflecting surface on the front of the building. Also notice the backs of the small mirrors on the slope opposite the concave surface.



Reflections in convex mirrors

Another Kind of Curved Mirror

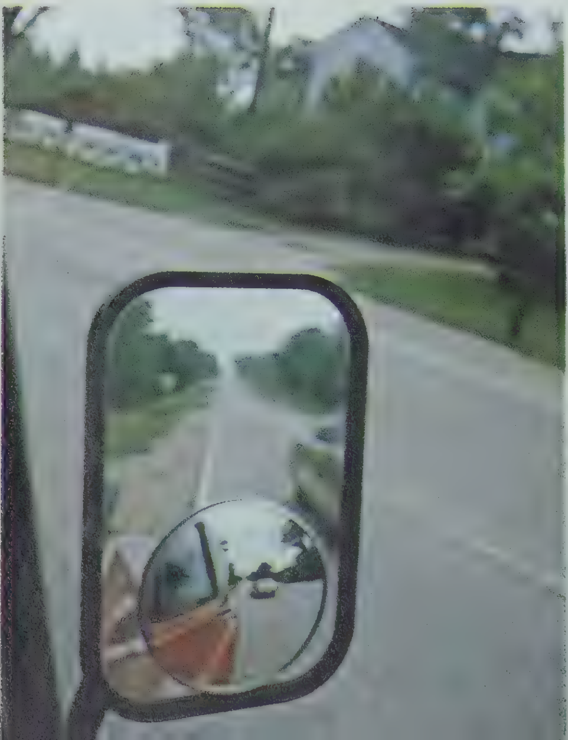
So far, you've studied about flat and inwardly curved mirrors. But there are also mirrors that are outwardly curved. That is, they are *convex*.

Many trucks and buses have rear-view mirrors that are partly flat and partly convex. In the flat part, the driver sees life-size images of what goes on behind the truck or bus. In the convex part, the driver has a smaller-than-life-size image of a wider part of the highway. With this wider view, he or she is not as likely to be surprised by a faster car suddenly trying to pass.

Outwardly curved mirrors are also used in some stores. Such mirrors are usually put high up at the back of the store so that the store clerk can see what goes on in all parts of the store.

The image that you see in a convex mirror is a virtual one. It can't be projected onto anything the way the real image caused by a concave mirror can be.

2·31



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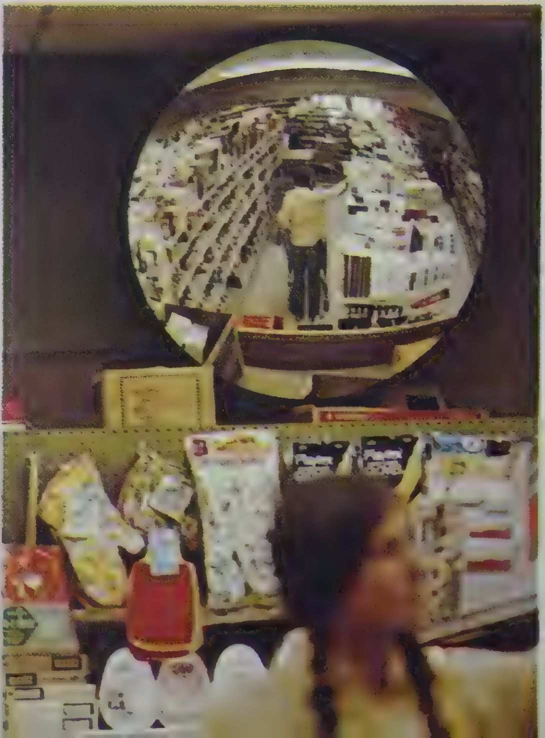


ON YOUR OWN

Images from a curved mirror

Get a concave shaving or make-up mirror. Usually such mirrors are only slightly concave. But if the mirror gives you a magnified image when you hold it close to your face, you can be sure it is concave. Now do the activity described in the second paragraph on page 44.

Next try to cast an image on a white card or piece of paper.

Take it and the mirror to a window. Close the curtains or pull down the shade so that only a narrow slit remains open.

Hold the mirror so that it faces out. Hold the white card in front of the mirror, but slightly above so that light from the outside can strike the mirror.

Turn the mirror upward very slightly and move it back and forth within 15 to 40 centimeters of the white paper. You should get an image on the paper of the scene outside the window.

ON YOUR OWN

Eyeglasses as mirrors

All clear glass reflects some of the light shone on its surface. So a piece of glass can be used as a mirror. You can use an eyeglass lens, in fact, as a pair of double mirrors. The lens should be the kind used in glasses for near-sighted people. That is, they should be the kind used by a person who can't see well far away.

Look at the lens from the side which would be the "outside" if a person were wearing the glasses. There are now two surfaces facing you, both convex—one on the side nearest you, the other on the far side. Both can act as convex mirrors.

You can see the mirror effect best if you have a dark surface behind the lens. Then the reflections of the objects behind you will be most noticeable.

Use the glasses to see an image of yourself. You will see two images, one from each convex surface of a lens. Are the images upside down or not? Move the glasses around a bit and see how the images move. Which image do you think is the reflection from which surface?

Turn the glasses around so you're looking at the concave side. Again you will see two images. Are these upside down? Move the lens around and observe how the images move. Which of the two surfaces is producing which image?

3

It can be a beach party or a graduation, a family picnic or a holiday dinner. Chances are someone will have a camera for recording the happening.

The camera might be a sensitive one with many adjustments. Or it might be a very simple one on which you just press a button. The function of both is the same. Both capture and record images.

The basic ideas that make any camera work are simple. In fact, they are so simple that you can make a crude working camera out of a cardboard box. The two main things you have to do is make a pinhole in one end of the box and fasten some photographic film inside the other end.

This chapter is about some things that happen when light passes through a small opening. With these observations you will be continuing your investigations of "what is light?"

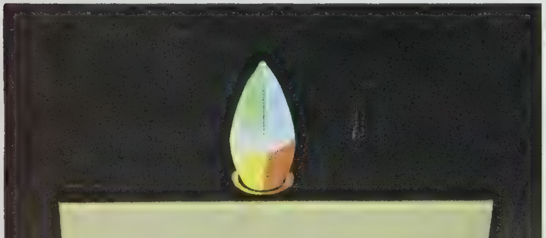
"Catching" an image through a pinhole

The design of cameras is based on the idea that light reflected from an object can produce a likeness of that object on another surface. In the camera, this surface is the photographic film.

You can use concave mirrors to form images that you can "catch" on another surface (chapter 2). In the next chapter you will investigate how lenses do the same thing. But right now take a look at some real images produced with nothing fancier than a card with a hole in it. A small hole made by a pin is just the right size.

When light from a bright object passes through the pinhole, it forms a real image of the object on any card, wall, or film that is placed behind the pinhole. The images in figures 3·1 and 3·2 were formed in that way.

Notice that almost all the light reaching the second piece of cardboard comes through the pinhole from the object. If there were much light coming from other places, you would



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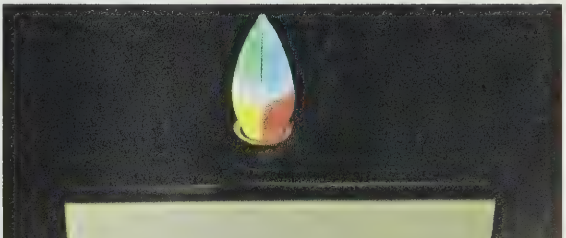

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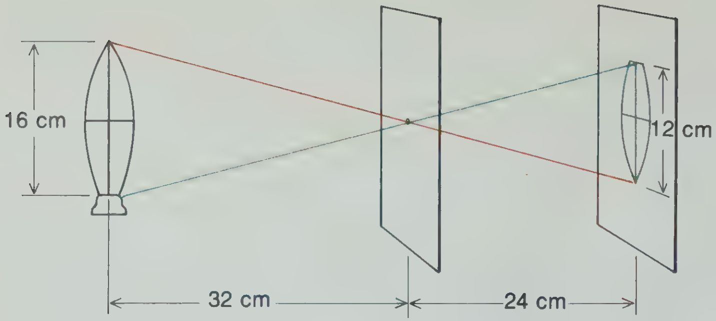

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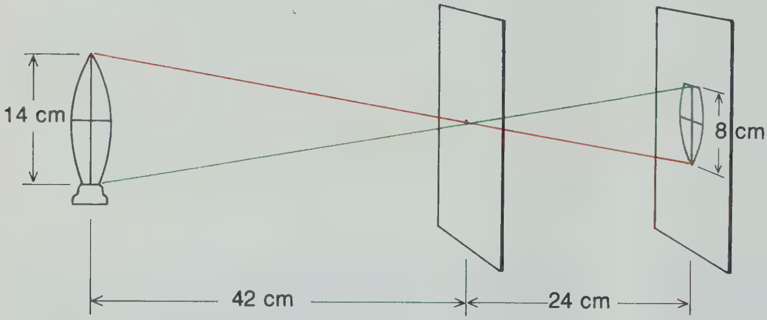


3·4

lose the image. There would not be enough difference in brightness between the image and the background.

With your eyes, trace the path of a light ray from the top of the object, through the pinhole, to the cardboard on which the image is falling. Also trace the path of a ray from the bottom of the object through the pinhole (figures 3·3 and 3·4).

Notice the direction of the image compared to that of the object. How would you describe this pinhole-produced image? In what ways is it reversed?

When an object is moved farther from the pinhole or closer to it, the size and sharpness of the image on the screen change. Similar effects take place when the surface which receives the image is moved back and forth.

The photographs and drawings show some important relationships between object and image. Take the object which is 16 centimeters tall and 32 centimeters from the pinhole, for example. The image is 12 centimeters tall and 24 centimeters from the pinhole. The object's height is what fraction of its distance from the pinhole? The image's height is what fraction of its distance from the pinhole?

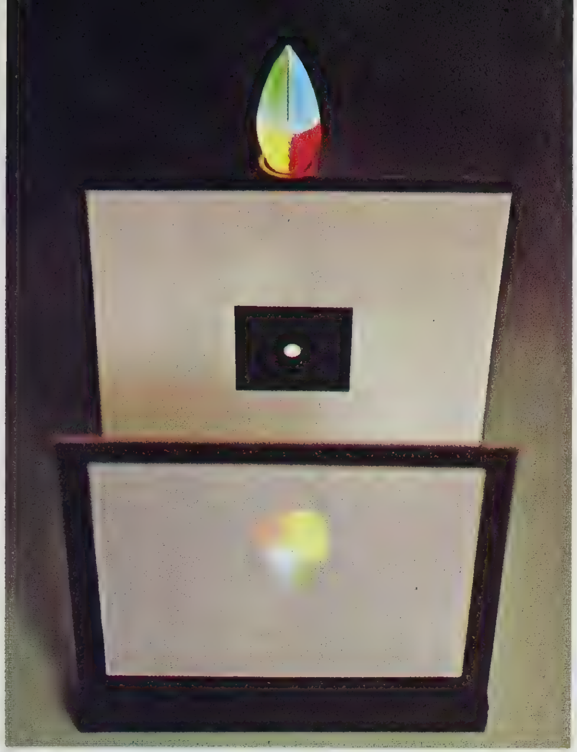
At this point, the question is whether the fraction ½ is special, or whether the equality of the fractions is the important thing.

Take another example. Suppose the object is 14 centimeters tall and is 42 centimeters from the pinhole. Its image is 8 centimeters tall and 24 centimeters in back of the pinhole. This time the object's height is ⅓ of its distance from the pinhole. And the image's height is ⅓ of its distance from the pinhole.

So it is the fraction of height over distances that is equal on both sides of the pinhole. This relationship helps you predict how the size of the image will change as you move the object.

You can also predict whether a pinhole image will be brighter or dimmer as you move an object farther from the pinhole.

Remember that only a fixed amount of light gets from an object through the pinhole to form the image. When you increase the distance of the object from the pinhole, the light that passes through the pinhole forms a smaller image, as we have just seen above. In other words, the light is concentrated on a smaller part of



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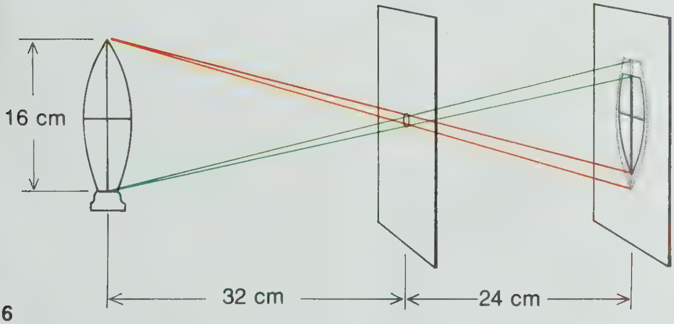


3·6

the wall or card. So while the image is smaller, it is also brighter. But if the same amount of light had to form a larger image, the light would be spread over a larger part of the wall or screen. So each part of the image would be less bright.

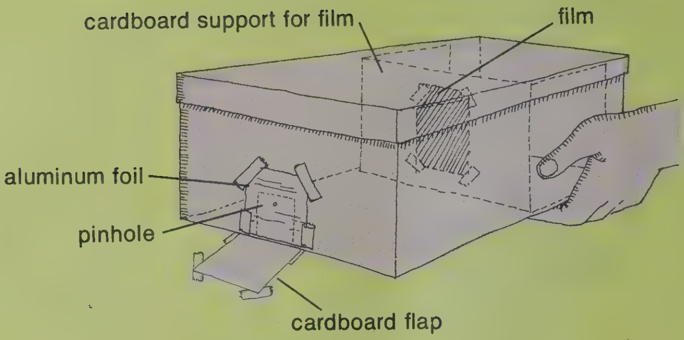
Another thing that can affect the size and sharpness of the pinhole image is the size of the pinhole. Notice in figure 3·5 what happens when the pinhole is larger than average.

If you would like to apply what you have learned about pinhole images, see the instructions on page 58 for building a pinhole camera.

TEST YOURSELF

1. *Will a pinhole image of an object become larger or smaller as you move the object closer and closer to a pinhole?*
2. *As you move the card on which you are "catching" a pinhole image closer and closer to the pinhole, will the image get larger or smaller?*
3. *As you move the card on which you are "catching" a pinhole image farther and farther from the pinhole, will the image get more or less bright?*
4. *What does increasing the size of the pinhole do to the image?*
5. *The pinhole image of a house on a card 3 centimeters from the pinhole is 1 centimeter high. The house is 36 meters from the pinhole. How tall is the house?*

ON YOUR OWN



How to make a pinhole camera

You will need the following materials:

- Shoe box or some other box about that size
- Piece of heavy cardboard slightly wider than the end of the box, but not higher than the end of the box
- Adhesive or masking tape
- Straight pin
- Aluminum foil
- "Slow" photographic film

PROCEDURE: Center a 3-centimeter (2-inch) square hole along the bottom of one end of the shoe box. Cover the hole with a piece of aluminum foil. Tape down the foil so that it stays in place. With a pin, punch a hole near the top of the aluminum foil insert. Bend each end of the extra piece of cardboard so that it fits upright easily inside the box.

Caution: Only the light coming from the pinhole should reach the film you will put in the box. So check all possible places where light might enter the box. Cover any cracks with adhesive or masking tape. You should also keep the pinhole covered until you are ready to point your camera at the scene you want to photograph. So tape a flap over the pinhole and temporarily tape the flap down.

Take the box, the roll of foil, tape, and scissors to a pitch-dark room. But before doing so, read the following:

In the dark, open the film and cut it into strips that will fit on the extra piece of cardboard. Tape one piece of the film to this piece of cardboard. Be sure that the film faces the pinhole. Wrap the pieces of film that you are not using in aluminum foil so that no light will reach them.

You will have to experiment with scenes of various brightness and at various distances from your camera. You will find that the distance of the film from the pinhole will also affect your results, as will the length of time you keep the pinhole open.

After you have taken a picture, retape the flap over the pinhole. Then bring the camera back into the pitch-dark room.

Open the box and take the exposed film off the cardboard. After you have carefully wrapped the exposed film in aluminum foil, you can take out a fresh piece of film and prepare to take another picture.

When you have taken as many photos as you want, take the film to a photography shop or the photography counter at some other store for development.

Huygens and Young challenge Newton's particle theory of light

What Is Light?
Part 3

Light can do some strange things

In your study of pinhole images, you probably found it fairly easy to get a mental model of how these images are formed if you thought of light as traveling in a straight line. Light from the bottom of an object seems to travel in a straight line through the pinhole to the image. In the same way, you could trace light from the top of the object through the pinhole to the image.

Shadows also seem to be evidence that light travels in a straight line. Hold up your hand next to a wall when there is a bright light behind your hand. You can draw a ray diagram of the possible path of light from the lamp, past your hand, to the wall. The obvious path seems to be a straight one (figure 3·7).

What you know about shadows and all that you have observed about pinhole images can be easily understood in terms of the particle theory of light—the theory that light is made up of very small particles. In the ray diagrams you have made and studied, the lines representing light rays show the possible path of the light particles. The lines are always straight ones.

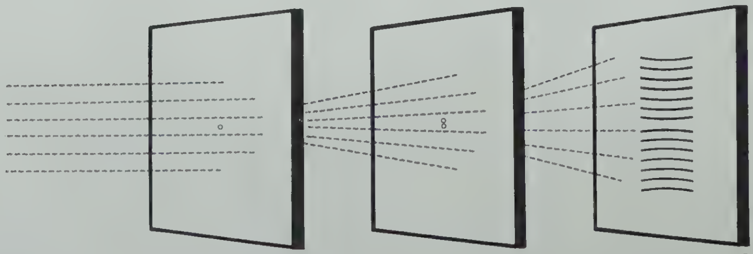
3·7

You can make an interesting observation if you take a closer look at the shadow in figure 3·7, or at any other shadow. No matter how crisp a shadow's edges may seem at first glance, they are not clean-cut at all. Especially with a magnifying lens, you can see that they are quite fuzzy. So the light in this situation is not traveling in absolutely straight lines after all. It is curving slightly as it passes the hand in the photo. Shadows always have such fuzzy edges, no matter how bright the light source is or how sharp are the edges of the object causing the shadow. This effect of fuzzy edges is called *light diffraction.* The particle theory of light can not explain it adequately.

Another experiment raises still more questions about the particle theory of light. Very bright light passing through two very small pinholes very close together comes out not as two spots, but as a series of curved lines (figure 3·8). Apparently the light from one opening interacts with the light from a close-by opening. This effect is called *light interference.*

Perhaps you remember that in the first chapter there was no explanation for the separation of white light into its colors by a device called a diffraction grating. In these gratings, light is separated into its colors by thin lines scratched very close to each other. Here again the smallness and closeness of the lines have something to do with the effect you see.

But can light particles create all these different situations? This is a question that bothered scientists for many years. But someone always has a theory.



3·8

The waves roll in

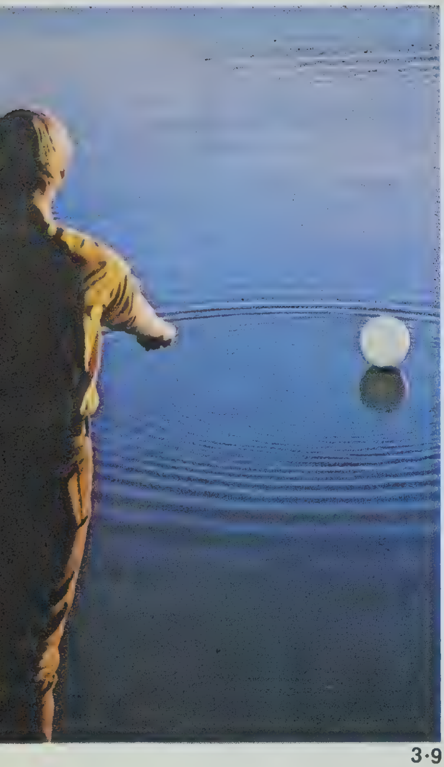
One of the things that fascinated early philosophers and scientists about light was its way of affecting things at a distance. How could the light from a bonfire, a torch, the sun, or the stars be seen from far away? How could the energy from the sun or a bonfire make a person feel warm? How does light get from one place to another? How can light "act at a distance"?

You can use a common situation to explore the problem of affecting something without ever going near it. Suppose you found a ball floating in the middle of a pond, and you wanted to make it jostle about. One way would be to wade in after it. But this pond is deep and dark, so you decide to "act at a distance." One way to keep dry and to make the ball move around would be to poke it with a stick. But there aren't any sticks around that are long enough. The pond does have plenty of pebbles and rocks around it, though. So you try throwing some rocks at the ball. You score a few hits, and you've made the ball move around from a distance.

If you accept the idea that light is made up of particles, you could compare the rocks and pebbles, thrown at the ball, to light particles traveling through a distance to strike something. Rocks and pebbles will bounce off the ball when they hit it. Light also bounces off surfaces, such as mirrors, when it hits them.

You'll remember that Isaac Newton worked with the theory that light is made up of particles. The idea first became popular when Newton suggested it in his book, *Opticks*, published in 1704. He based his theory in part on observations of the straight path which light seems to follow to strike mirrors and to be reflected by them. His theory did not explain all his other observations about light. But it seemed a possible theory to him.

Newton, who was a very well thought of scientist during his lifetime and after, might have had doubts about his theory. But his followers did not. The particle theory was what one was supposed to accept. Fortunately for science, if not so happily for our peace of mind, there were a few doubters. Let's go back to the ball in the pond for an idea of another way to affect something at a distance—as light does.



3·9

At the pond, some of the rocks you throw at the ball are bound to miss. They fall in the water near the ball, and make waves. The waves jostle the ball just as the rocks did: That gives you an idea. You stand at the shore of the pond and make waves. The big ones spread out into the pond and reach the ball, making the ball jostle about.

Christian Huygens (hī′genz), a Dutchman who lived during Newton's time, thought the mental model of waves could be applied to light. He did not follow the light-is-particles crowd. However, his model stood unsupported until 1802. That year, Thomas Young took up the banner for the wave theory of light. (Young was also the first to scientifically explain how the human eye sees color.) He had observed the light-and-dark patterns when light passes through very small openings that were discussed in the previous section (figure 3·8).

Before getting into light waves, however, let's look at water waves more carefully. We cannot see light waves. We can see only some things which might be caused by wave behavior of light. But water waves are visible. What we can learn from observations of water waves, we can use to better understand some things about light.

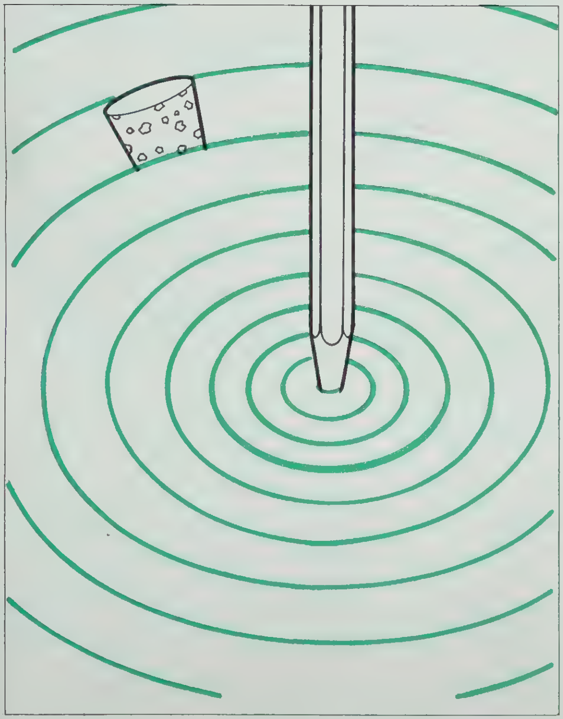
What's a wave?

Even if you do not live near the seashore or near a large lake, you certainly have seen waves. Waves are the regular ridges and valleys on the water surface. You can also make and observe waves in a bathtub, a sink, or a puddle. To help your observations, you should have a very small piece of cork or a small twig floating in the water.

First, notice that when you dip a pencil point in the water, the *waves spread outward in all directions from the pencil.*

Second, notice that the regular motion up and down does not move the piece of cork or the twig across the water. It only bobs up and down in the same spot. You can infer from this observation that *waves don't move any water across the surface* either. (If you live near the seashore, you know that there is usually a current and an undertow that can move things from place to place in the water. In some cases these are related to waves, but they are not waves themselves.)

The third thing to notice is what happens *when one wave meets another wave.* You can create two sets of waves at once by dipping two pencils into the water at the same time a little distance apart. *You will see a new pattern of peaks and valleys.*



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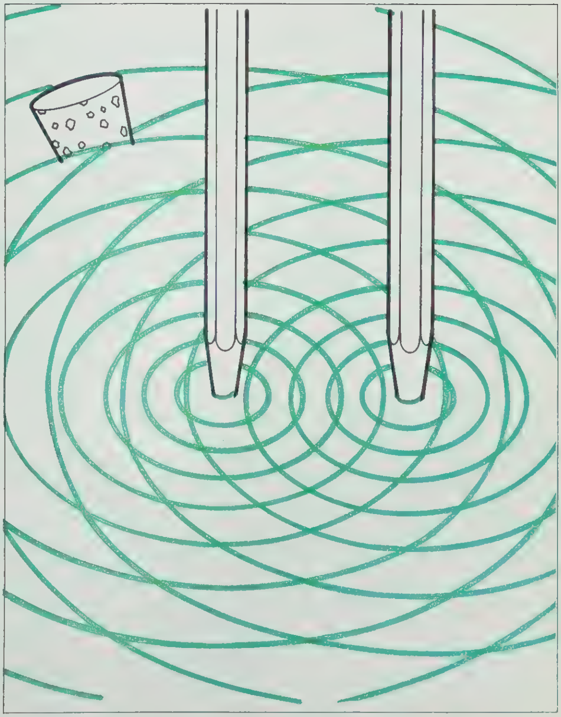

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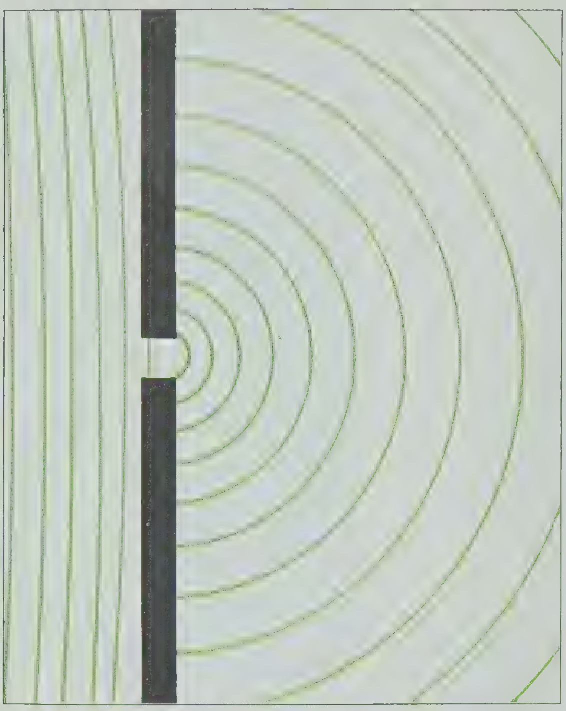

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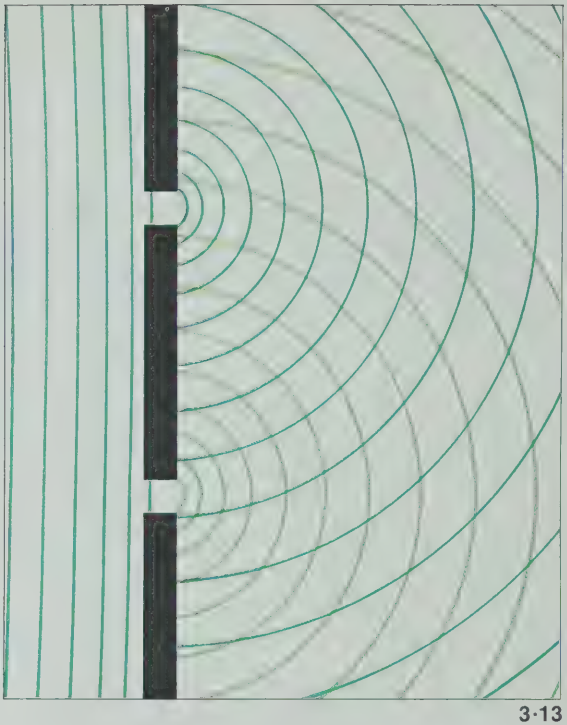


3·13

Then notice what happens when a water wave passes through a small opening in a barrier. *Even when a small part of a wave* that could be considered practically straight *goes through the opening, it emerges on the other side of the opening not straight but curved.* In fact the wave looks as if it had been formed by a pebble dropped where the hole is in the barrier.

Finally notice what happens *when a wave passes through* two *small openings* in a barrier. This new pattern will be different but predictable if you remember what happens when waves pass through one opening: The waves will start expanding in a semi-circle from the holes (figure 3·13). Notice that when the *new waves start expanding from the two side-by-side holes,* they don't touch. But *a moment later* they do. And still later *they've overlapped quite a bit.* Look at the points where the highest part of one wave meets the highest part of another. These points form definite patterns.

Through all these observations one thing remains the same. A wave started in one part of a body of water can cause motion along a large surface of that body of water. To make something move requires energy. Thus water waves must transmit energy.

The particle theory is challenged

The light-and-dark patterns that Thomas Young observed when light passes through very small side-by-side holes reminded him of certain wave effects. In particular they reminded him of the pattern formed by water waves interfering with each other after passing through two small openings.

Young compared the areas where the high points of water waves cross to the bright areas in the light pattern. The intersection of the high points of two water waves is in line with other such intersections. Young compared the dark bands of a light interference pattern to those areas where water waves are not forming this pattern of intersections.

Diffraction, the effect that you sometimes see when light seems to bend around an edge, Young compared to the curving of water waves when they pass through *one* small opening. From such observations, Young was sure that Newton's particle theory wasn't all in the right.

On one point, however, he did agree with Newton. He too believed that white light is made up of colors. But Young went one step further. He suggested that the different colors of light were waves of different lengths. For example, the high points of blue light are much closer together than the high points in red light. Therefore, a diffraction grating—the device with many small etched lines—can separate white light into its spectrum by separating out the different wavelengths.

Young's work gave the first clear-cut evidence for the wave model of light over the particle model of light. The wave model would have shattered Newton's particle theory right away. But Young had gotten himself disliked by an important politician-scientist named Henry Brougham (brü′əm). Young had criticized some of Brougham's writings too strongly. Brougham got back at Young by making fun of Young's experiments. Young's conclusions were not taken seriously for another 15 years. But Young was to have his day, as you will see in the next chapter.

ON YOUR OWN

You can make light bend

All you need for this activity is a cloth handkerchief and a streetlight. At night when the streetlight is on, hold the handkerchief in front of your eyes and look at the light through it.

Compare what you see through the handkerchief with what you see when you look directly at the light. Now turn the handkerchief slowly in front of your eyes as you look at the streetlight through it. Notice what is happening to the pattern you see.

The pattern you have seen is caused by the bending of light as the light passed through the mesh of the handkerchief fabric. That bending is called diffraction.

You can get a slightly different effect with the following materials:

Flashlight
Cardboard, 2 thick pieces 30-cm
  square (12-in square)
Straight pin
Tape
Marking pencil
Scissors

PROCEDURE: Take one card and make two tiny pinholes in it, as close together as you can make them. With the pencil, draw a circle around the holes so you can find them easily. It might be a good idea to make several pairs since it's difficult to make the holes both small enough and close enough together in one try.

Trace the head of the flashlight on the other card, then cut out the traced shape. Make one pinhole in the center of this cardboard shape. Tape this cardboard in front of the flashlight so that the light shines through the pinhole.

Put the turned-on flashlight on a table at one end of a large dark room. Step back from the light 3 meters (about 10 feet).

Put the card with the pinhole pairs in front of one eye. Close your other eye. Move your head around until you see the light from the flashlight. The light should look different than it does without the pinholes in front of your eye. Remove the card and see if there is a difference. If not, try another pair of pinholes.

The pattern of light that you get by looking through the pair of pinholes is due to light interference.

Chapter 4: Lenses

4

Pinhole cameras can be interesting, but they are not as handy as ready-made cameras for getting good photos.

When the light reflected or given off by some object passes through a pinhole, you can get an image of that object on a flat surface. The image is always upside-down.

As you move the pinhole back and forth between the object and the surface on which its image is falling, the image changes in size and clearness. However, the image is not very bright, even when the pinhole is in the best possible position.

If you were to take a conventional camera apart, you would find that it is essentially a pinhole camera with a lens where the pinhole should be. The lens in place of the pinhole apparently does something to gather more light than does a pinhole. With a lens in place of the pinhole, the image is brighter.

Lenses have two obvious qualities which determine the effect they have on light. First, lenses are made of transparent material such as plastic or glass. Second, they are always smoothly curved. But how do these two qualities make lenses give the results they do? That's the subject of this chapter.

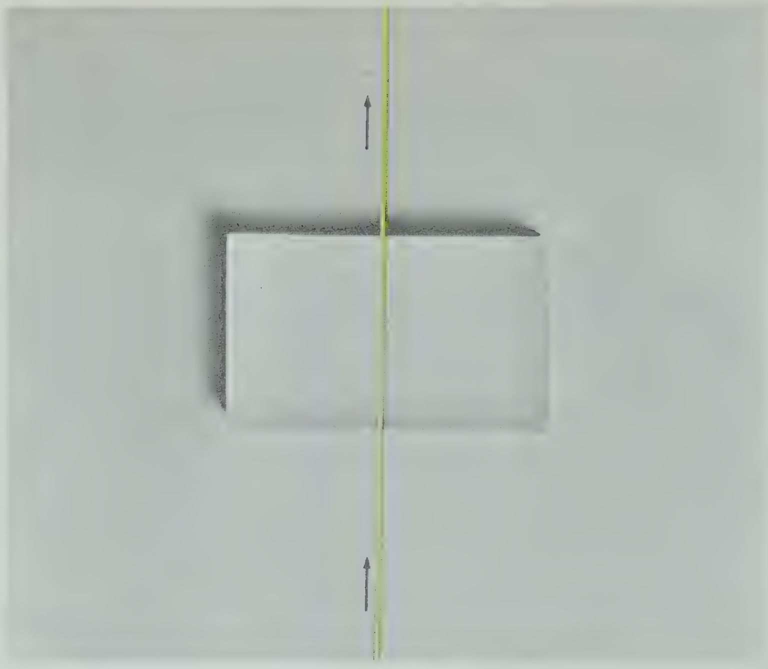
Angles of light

Let's first consider the transparency of a lens. This series of photographs shows a transparent glass block as you would see it if you looked down on it from above.

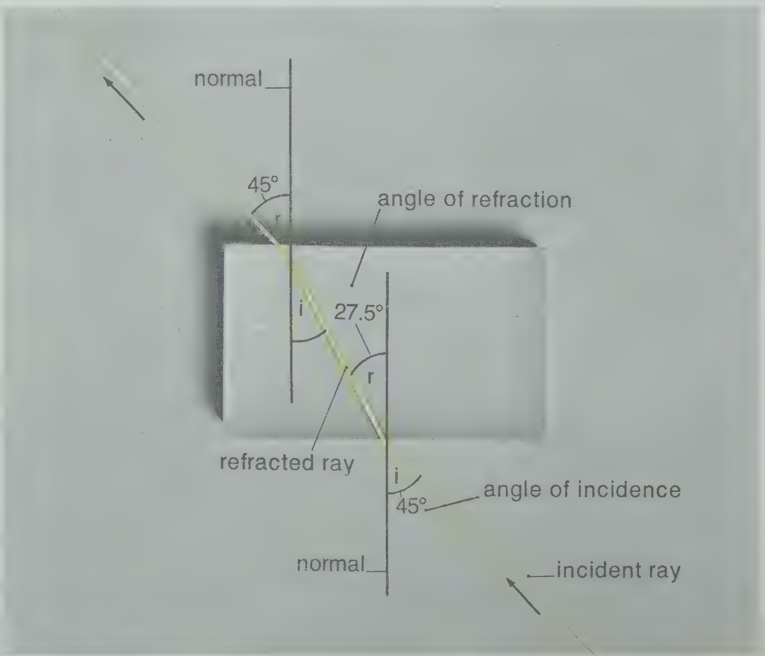
Some straight lines have been drawn perpendicular to two surfaces of the glass block. As you might remember, a line drawn perpendicular to a surface is called a *normal* to that surface. Normals are handy when you deal with angles. In this case, use the normals to compare the angle of light in the air to that in the glass block.

When the narrow light beam strikes the glass block along the path of the normal, nothing unexpected happens. The light goes straight through the glass block. However, the other two photographs show something different. In these you have to consider the angle at which the light beam travels.

When you were investigating how light is reflected from mirrors, you measured the angle of incidence and the angle of reflection. These are the angles between the normal line and the path of light rays. You can also measure angles of incidence for the



4·1 Light beam striking glass block along imaginary *normal*.



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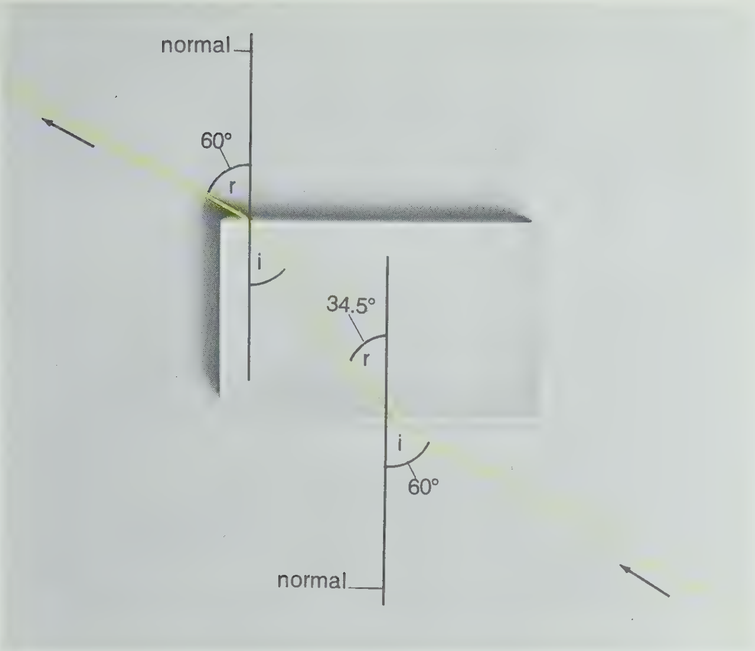


4·3

ON YOUR OWN

A penny for refraction

You will need a penny, a cup, transparent tape, and a pitcher of water.

Tape the penny inside the cup at the bottom. Then move your head to just that point where you can no longer see the penny over the rim of the cup.

Then very slowly pour the water into the cup. Keep looking into the cup over its rim. Does the penny come into view? Why?

light rays in the second two photos. These angles are always labeled *i*. They are the angles between the path of the incident (incoming) rays and the normal line.

Notice that the angles of incidence can be either in the air or in the glass block. When the light is leaving air and entering the glass, the angle of incidence is in the air. When the light is leaving the glass and entering the air, the angle of incidence is in the glass.

The photographs show that the light beam bends as it passes from air to glass or from glass to air if it hits the surface between them at an angle. The angle between the *refracted* (bent) ray and the normal is called the *angle of refraction*. The angles of refraction in these photographs are always labeled *r*. Notice that they are always the angles after a light beam has passed from one material to another. And they can be in either the air or the glass block.

From these photographs, and experiments you might have done yourself, try to think of a way the angles of incidence always compare with the angles of refraction. For example, are the angles of refraction larger or smaller than the angles of incidence when the light enters glass from air? Are the angles of refraction larger or smaller than the angles of incidence when light enters *air* from glass?

This is another way to ask the same questions: Does light bend away from or toward the normal when it enters glass from air? Does it bend toward or away from the normal when it enters *air* from glass?

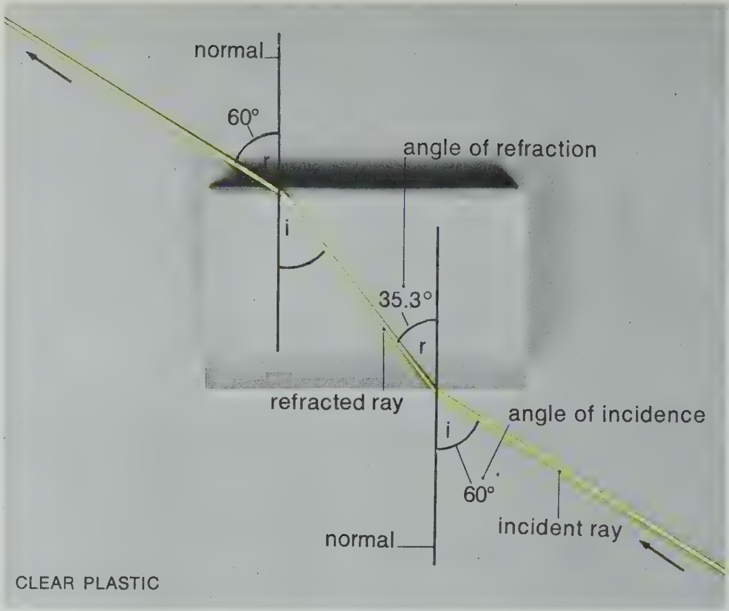
Angles of light in various materials

The transparent blocks in these photographs look almost the same. But notice what happens when a narrow beam of light traveling through the air strikes each block. As the light beam enters each block, it is bent. But it is bent a slightly different amount in each block.

The blocks might look the same, but they are not the same. One is solid clear plastic. The other two are very thin plastic boxes filled with a liquid. One is filled with water, the other with castor oil.

If you were to shine light into the same materials at the same angle you should get results similar to the ones in the photographs. You would find that the amount of light bent (or refracted) by a transparent material depends upon the material. Some refract light more; others less.

People working with transparent materials often want to compare refraction in one material to that in another. The extent to which a material refracts light is indicated by a number called the *index of refraction.* The more sharply a material refracts light toward a normal, the higher is its



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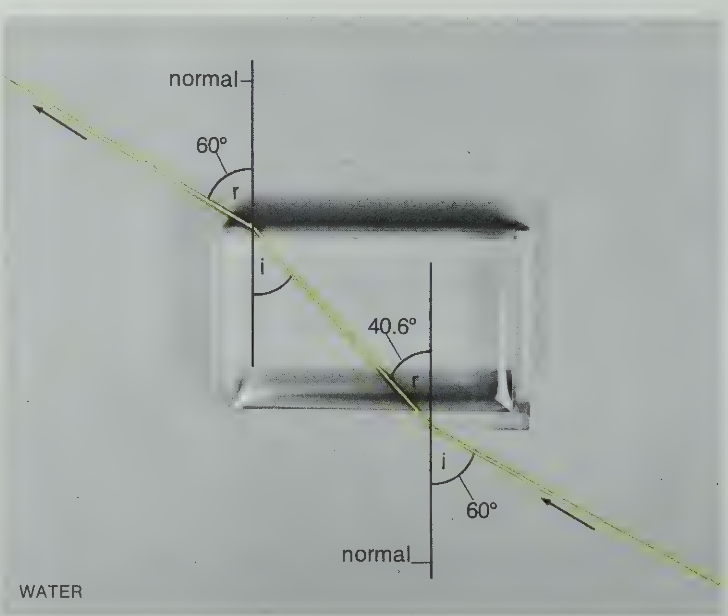

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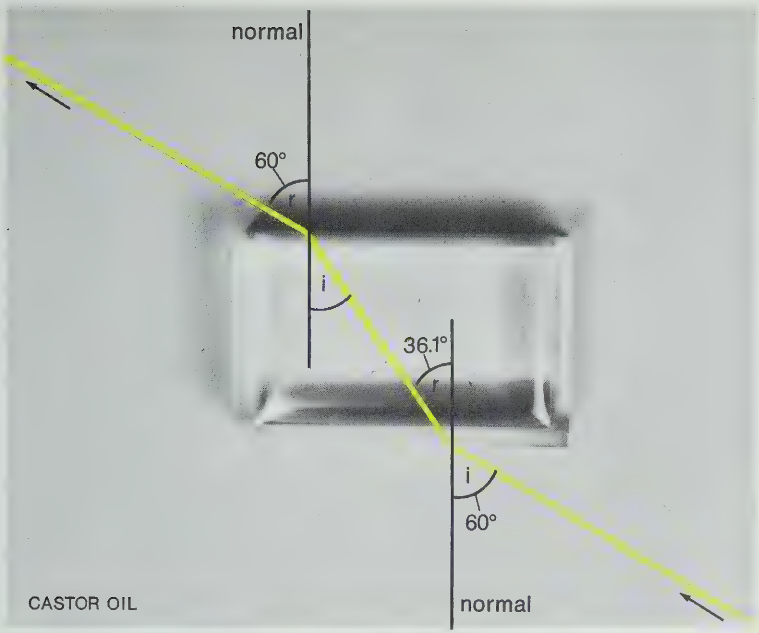


4·6

index of refraction. For example, the material which bends the light beam the most also has the highest index of refraction. Compare figures 4·4 through 4·6 with Table 1.

Table 1

	Index of Refraction
Castor oil	1.47
Common glass	1.53
Diamond	2.42
Emerald	1.58
Isopropyl alcohol	1.37
Plexiglass (plastic)	1.50
Quartz	1.46
Ruby	1.76
Water	1.33

Basically, the index of refraction is a comparison of the path of light in air to that in some other substance. Some substances refract light more or less than others. So the index of refraction is different for different substances.

TEST YOURSELF

1. *Define the terms "angle of incidence" and "angle of refraction" as used when talking about light entering* and *leaving a transparent material of any kind.*
2. *Draw a diagram to show approximately what happens when a narrow light beam enters a glass block in the following ways:*
   (a) head on,
   (b) at an angle of incidence of about 50 degrees.

Note: *Don't forget to draw a normal at the point where the light beam enters the glass.*

3. *Draw a diagram to show approximately what happens to a narrow light beam that enters the following substances at an angle of 45 degrees:*
   (a) a glass block,
   (b) a quartz block,
   (c) a very thin transparent plastic box filled with water.

See Table 1 for the refractive index of each of these materials.

Note: *Consider only the water in the last example. The plastic box will not interfere with the results too much because of its thinness. Also, don't forget the normals.*

4. *Now a little different twist: Suppose all three blocks in question 3 were put side by side so closely that there is no air space between the three blocks. Then a narrow light beam is shone through the blocks—from the glass directly into the quartz and from the quartz directly into the water. Draw a diagram to show approximately what happens to the light beam at each surface.*

Note: *It is very important to know whether the refractive index of the substance the light is leaving is larger or smaller than that of the one the light is entering.*

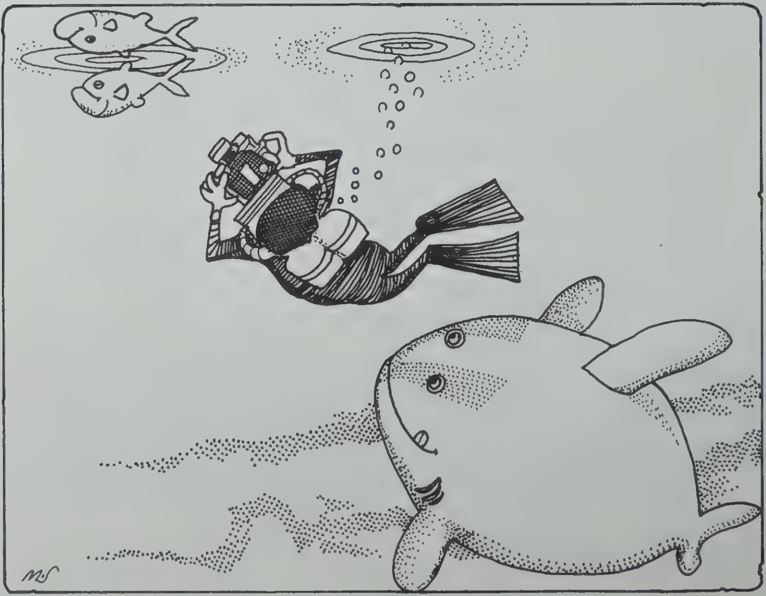
When an incident angle of light becomes too large, total reflection occurs

Zigzagging Light

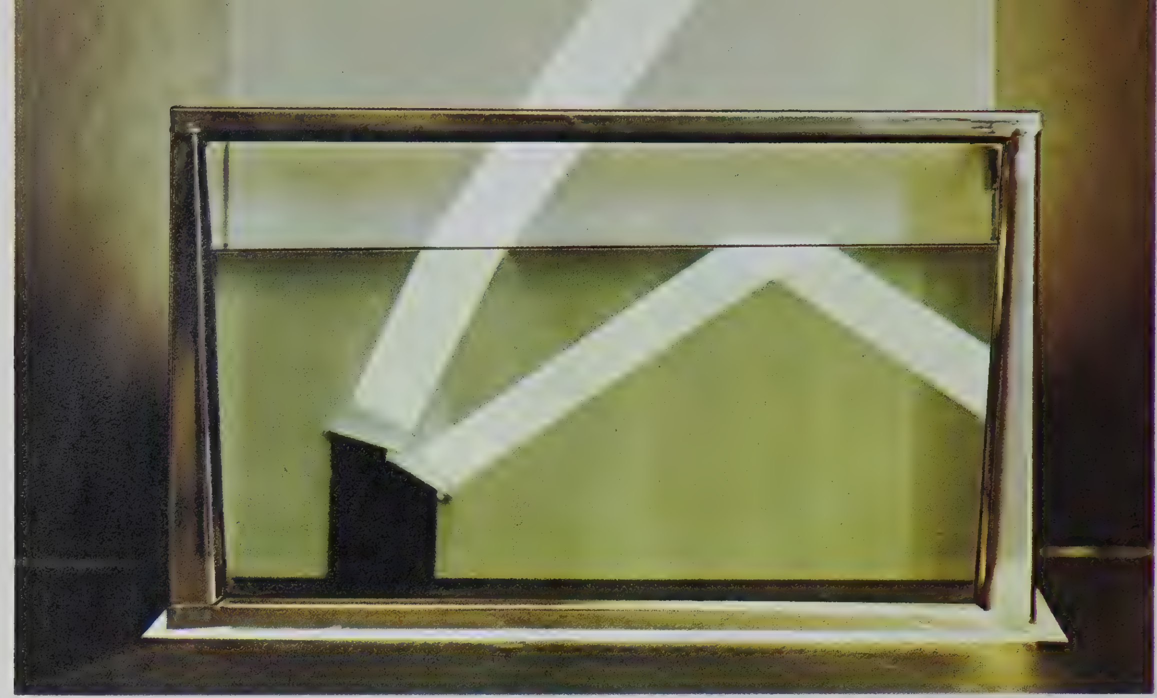
If you open your eyes when you're under water in a swimming pool or a lake, you will probably find that you can't see above the surface of the water. This will be true especially if you don't look directly above you. If the water is clear and still, however, you might see the mirror image of the bottom of the pool or lake.

You can also see this kind of reflection if you take a look at the under surface of water in a large fish tank or some other glass container. From the side of the container, try to see the surface of the water as a fish would. You should see the reflection of whatever is in the container. There is an explanation of these situations. This explanation involves refraction and reflection of light.

You've seen light refracted when it goes from air to some other material such as glass or water. You've also observed light leaving these other materials and being refracted in air. However, in the cases you have studied so far, the angles of incidence were never very large. They were never so large that the light was refracted more than 90°.



4·7



4·8

Now notice what happens when a light beam's angle of incidence is made larger and larger in a tank of water (figure 4·8). When the angle of incidence is past the point where the refracted beam in air would be parallel to the surface of the water, the whole beam of light is *not* refracted. It is reflected right back into the water. In other words, the inner surface of the water is now acting as a mirror. As mentioned earlier, if you look at the inner surface of a tank at the correct angle, you will see a reflection of whatever is in the tank. The result is the same as you would get if a mirror were there. This situation is called *total internal reflection.*

One of the most promising ways total internal reflection is used is in "piping" light through transparent plastic wires. As you can see (figure 4·9), most of the light that hits the inner surface of each plastic wire, hits it at such an angle that total internal reflection occurs. When the reflected light hits the opposite inner surface of the wire, the same thing happens. Most of the light is reflected back into the plastic. In this way, the light makes its way through each wire to the other end. Only there does it leave the wire and enter the air.

This way of bringing light from one place to another is called fiber optics. With fiber optics, light can be made to enter and leave small enclosed areas. For example, doctors have instruments which use fiber optics for viewing inner parts of the body which would otherwise not be visible without surgery.

4·9

The particle theory does not explain refraction very well

What Is Light? Part 4

Refraction—and the waves roll on

Refraction of light is common and put to good use in the modern world. However, it used to make scientists uneasy. Let's go back into history again for this story.

The year was 1850. The results of several interesting experiments with light had been published. Two French scientists, Jean Foucault (fü kō′) and Armand Fizeau (fē zō′), had measured the speed of light in air and in various other transparent materials. Their results showed that light travels faster in air than in any other material.

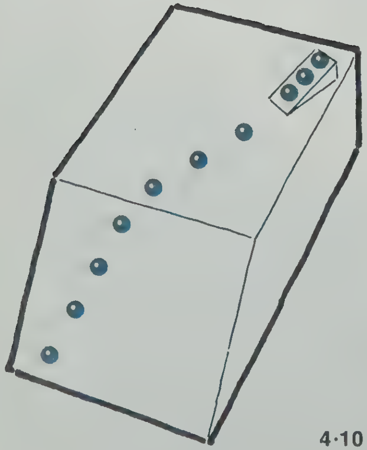
The supporters of light-is-waves were pleased. They said that now it was proven that light is a series of waves. The light-is-particles crowd felt very uncomfortable. And for good reason.

Newton's theory

As you'll recall from your study of mirrors, Sir Isaac Newton thought that light is made up of small particles traveling in a straight line. And he showed that light bounces off a mirror in a straight line at the same angle that it hits. Balls can be used to represent light particles. When balls are rolled against a wall along a flat surface, they are also reflected at the same angle that they hit. The particle model works well here.

But the particle theory had to explain another observation. It had to explain the change in direction when light travels from one transparent substance to another. That is, it had to explain refraction.

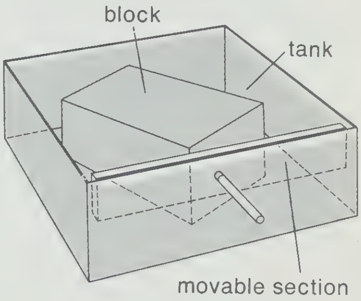
The particle believers did have an explanation for this observation. According to them, light traveling from one transparent substance to another can be compared to balls rolling down the kind of slope shown in figure 4·10. The top level surface represents air. The steep edge represents the other substance. So, whenever light passes from air into another substance and bends toward the normal, it must be speeding up. Light does bend this way when it passes from air into water or some other transparent material. And balls on the slope do speed up on the section that is slanted.



4·10

There is one catch, however. In Newton's time no one had accurately measured the speed of light in air and in other materials.

4·11a The movable section is pushed back and forth in the tank to cause ripples across the top of the water. The block in the tank provides an area where the water is shallow.



So no one knew for sure whether light did or did not travel faster in other materials than in air. But Fizeau's and Foucault's findings are important here. Their discovery that light travels faster in air than in any other material was evidence that Newton's particle theory did not suit as an explanation of refraction. Here's where the wave model does a better job.

Newton is challenged

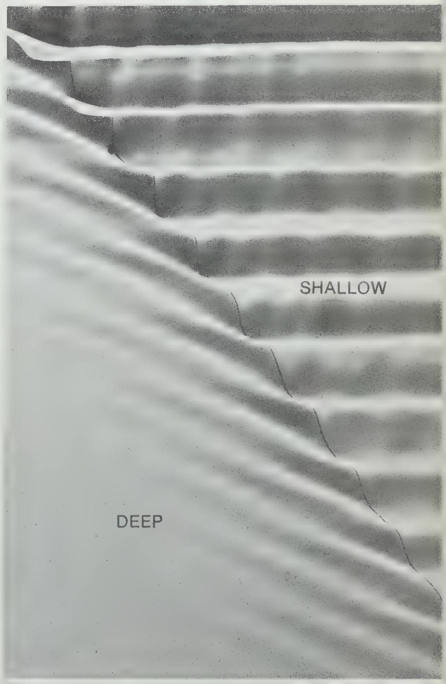
To discuss the wave model of light, we can again use water waves as a comparison. Scientists have observed that the speed of waves across the surface of a liquid depends upon the depth of the liquid. The shallower the liquid is, the slower the waves are. So if we make one half of a water-filled tank deep and the other half shallow, we can use it as a model (figure 4·11). We can infer that we are seeing something similar to what might be happening when light waves pass from air to some other material. The deep end of the tank represents air. The shallow end represents some other transparent material.

The wave theory works quite well in this situation. When the waves reach the shallow end, they bend the predicted way. They have the same direction as light does when it is refracted after leaving air. And the waves are slower—*not* faster—in the section representing the substance other than air.

Besides refraction, the wave theory can explain interference and diffraction (see pages 59 to 65), which the particle theory can not. So by the end of the 1800's, scientists agreed that the search was over. They knew light is a series of waves. They could go on to other problems.

But again surprises were in store. This time, though, the surprises were more challenging than just evidence that this or that side of an argument had gained the upper hand. What was to happen in the first half of the 1900's was to change some very basic ideas about the world that people had had for centuries.

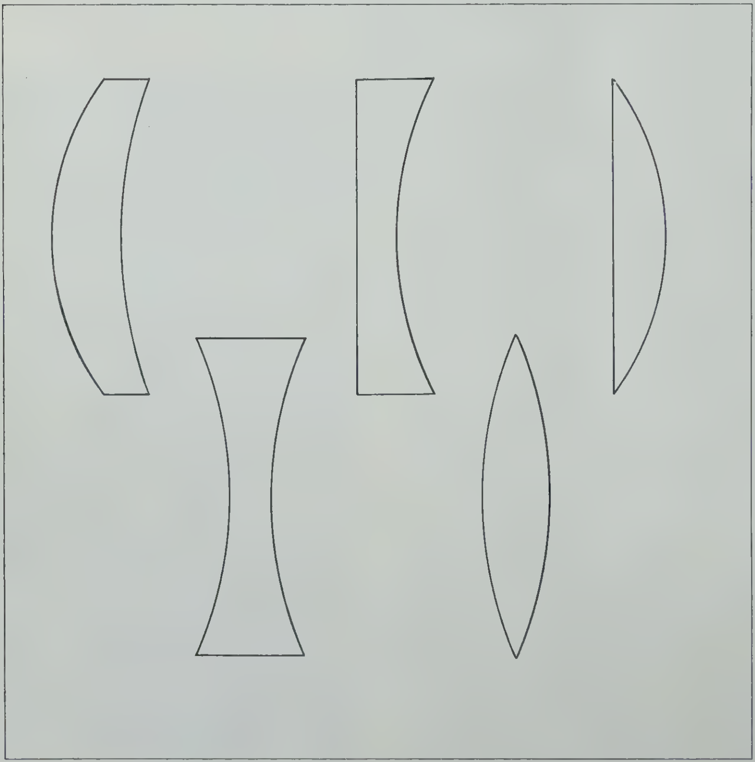
And it was to be done in large part because an unknown office worker, sitting at his desk in Bern, Switzerland, was doing some serious thinking. The story continues in the next chapter.



4·11b

At the beginning of this chapter, we said that lenses have two obvious properties: They are transparent and they are smoothly curved. In the first section of this chapter, you examined what happens to light when it hits a flat surface of a transparent material. Now let's see what happens when the surface is not flat, but curved.

Lenses can have two kinds of curves: inward or outward. But unlike mirrors, lenses can also have both of their surfaces curved in the same way: both sides curving out or both sides curving in. In this section, we will examine those lenses with both sides curving out. These lenses are called *double-convex.* They are the kind used for magnifying glasses and cameras.

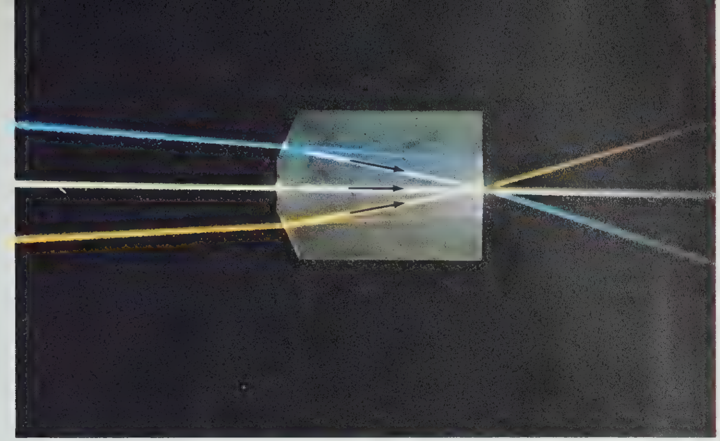


4·12 Lenses of various shapes.

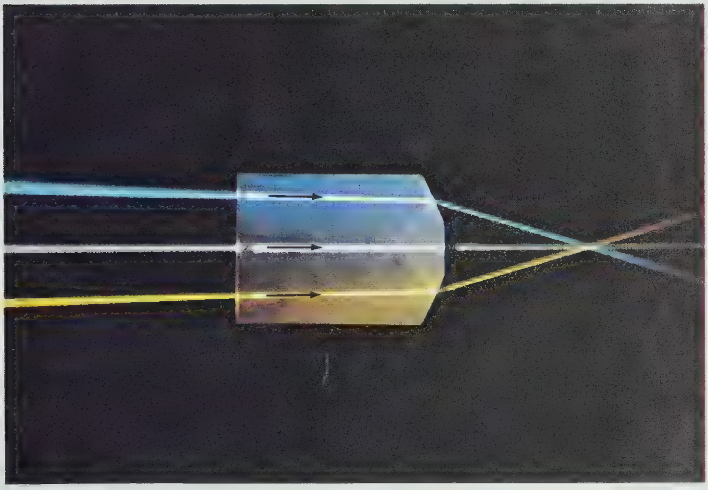
You can think of a convex (outwardly curved) lens surface as made up of a countless number of straight sections, each facing a slightly different direction. Figures 4·13 and 4·14 show what effect such segments could have. Notice how parallel light beams bend when they strike the three straight surfaces which form a semi-circle at the end of a transparent block.

Then try to trace the parallel light beams which pass through the outwardly curved sides of a double-convex lens (figure 4·15). This kind of lens brings parallel light beams together at a point.

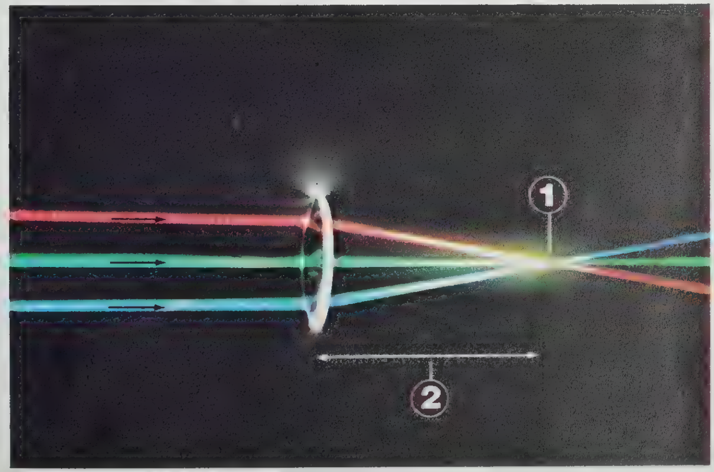
The point where the once-parallel beams meet after passing through the lens is called the *focal point* of the lens. There are two focal points, one on either side of the lens, since light can pass through the lens from either side. The distance from the center surface of a lens to the focal point is called the *focal length.*



4·13



4·14



There is one other thing to remember here. Light beams that go through the exact center of the double-convex lens, at *any* angle, are not bent. The result is the same as if the light were going head on into a transparent block with opposite sides parallel.

TEST YOURSELF

1. *Describe the shape of a double-convex lens.*
2. *What does a double-convex lens do to light beams which strike its surface parallel to each other?*
3. *How many focal points does a double-convex lens have? Why?*
4. *What happens to light beams which go through the exact center of a double-convex lens?*

4·15 The point where light beams parallel to its center line meet after passing through a lens is the focal point of the lens. It is identified by ①. The distance from the center surface of the lens to the focal point, identified by ②, is the focal length of the lens.

Camera images with double-convex lenses

4·16 Double-convex lens casting a real image of a street scene on a white card.

You've studied how pinholes can be used to create a camera image. Here is a quick way to observe the image a double-convex lens can form—the kind used in cameras. Use a common magnifying glass. It is also a double-convex lens.

Stand at a window which has its shade or curtains almost completely closed. Hold a white card in one hand and a double-convex lens in the other so that the light which comes through the window goes through the lens and hits the card. Then move the lens back and forth in front of the card until you see an image on the card of the scene outside. Move the lens back and forth a little more, until you get the clearest possible image on the card. With the help of a friend, measure the distance between the lens and the card.

When you try to get an image of any distant object, at least 6 meters or so away from you, the image always falls at this same distance from any one lens—at its focal point. However, when you try to get an image of something much closer to the lens, say several focal lengths, you'll get different results.

To predict how and where a double-convex lens will form images, you can use simple ray diagrams. To make such diagrams, you need to remember three things: (1) Parallel light rays pass through a double-convex lens, meet at the focal point on the other side of the lens, and pass on. (2) Light rays which pass through the exact center of the lens—at any angle—are not refracted by the lens. (3) An image forms where light rays starting from one point are brought together again.

Figures 4·17 through 4·19 all show the same double-convex lens. These same drawings show its centerline (or axis) and the two focal points. Notice how the three rules just mentioned are applied in the diagrams. An object gives off or reflects light in many directions. So, just by chance, some of the light rays leaving the surface of the object in the diagrams will be parallel when they strike the lens. According to what you have already observed and read, these rays will pass through the lens, meet at the focal point, and then pass on—no longer parallel.

Also, just by chance, some of the light rays will pass through the exact center of the lens at various angles. These rays will not be refracted, but will pass straight through the lens.

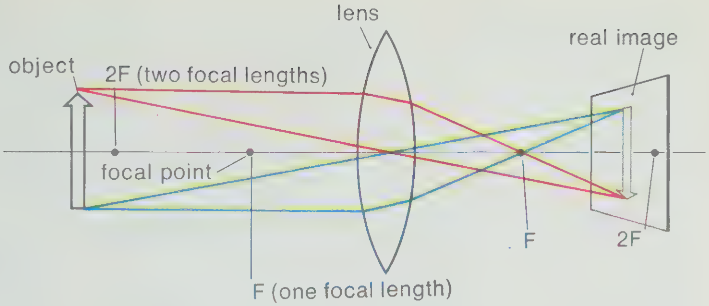
You need to follow just four rays to get an idea how a double-convex lens produces an image: two rays which come from the top and bottom of the object, and are parallel; and two rays, also from the top and bottom of the object, which go through the center of the lens.

The place on the other side of the lens, where the two rays from the top meet, indicates the top of the image. The place where the rays from the bottom meet indicates the bottom of the image. As you see in the figure, you can draw the image between these two points. Is the image reversed in any way?

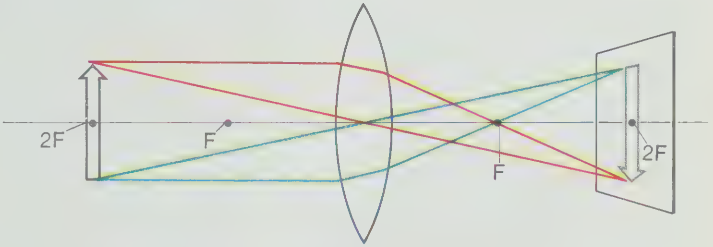
From the three diagrams in figures 4·17 through 4·19, try to find a relationship between the distance of the object from the lens and the size of the image. Does the image get larger or smaller as you move the object and lens closer?

Also, in each case compare the distance of the image from the lens and the distance of the object from the lens. Does the image fall farther from or closer to the lens as you move the object closer to the lens?

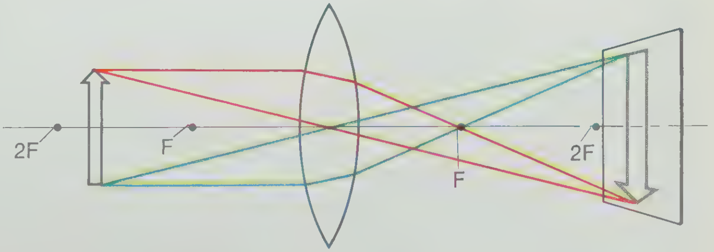
All the images in these diagrams represent real images. Real images are ones you can see or "catch" on a surface such as a card, wall, or photographic film.



4·17 Notice that the parallel rays that meet at the focal point of the lens are parallel to the center line of the lens.



4·18



4·19

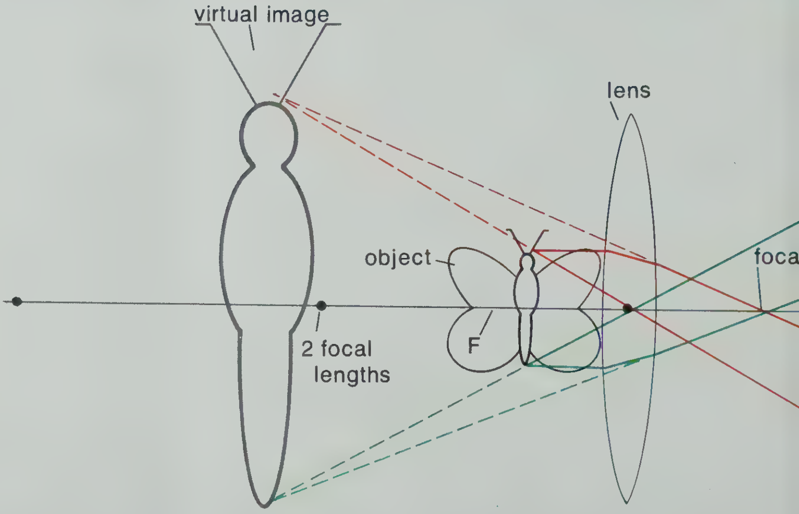
Double-convex lenses as magnifiers

In the diagrams on page 81, the object producing the real image was always a little farther than one focal length from the center of the lens. Now notice what happens when the object is less than one focal length from the lens. Light rays parallel to the centerline of the lens are refracted and meet at the focal point on the other side of the lens. Rays that pass through the center of the lens are not refracted and go straight.

So far there doesn't seem to be anything different from the situations you saw in the previous diagrams. But keep following the two kinds of rays from the top and bottom of the object. They do not meet after they pass through the lens! But the two kinds of rays must meet—or seem to meet—if you're to see an image. They do if you trace an imaginary path for both of them backward behind the object.

Compare the size of the image to the size of the object. Also notice whether the image is right-side-up or upside-down.

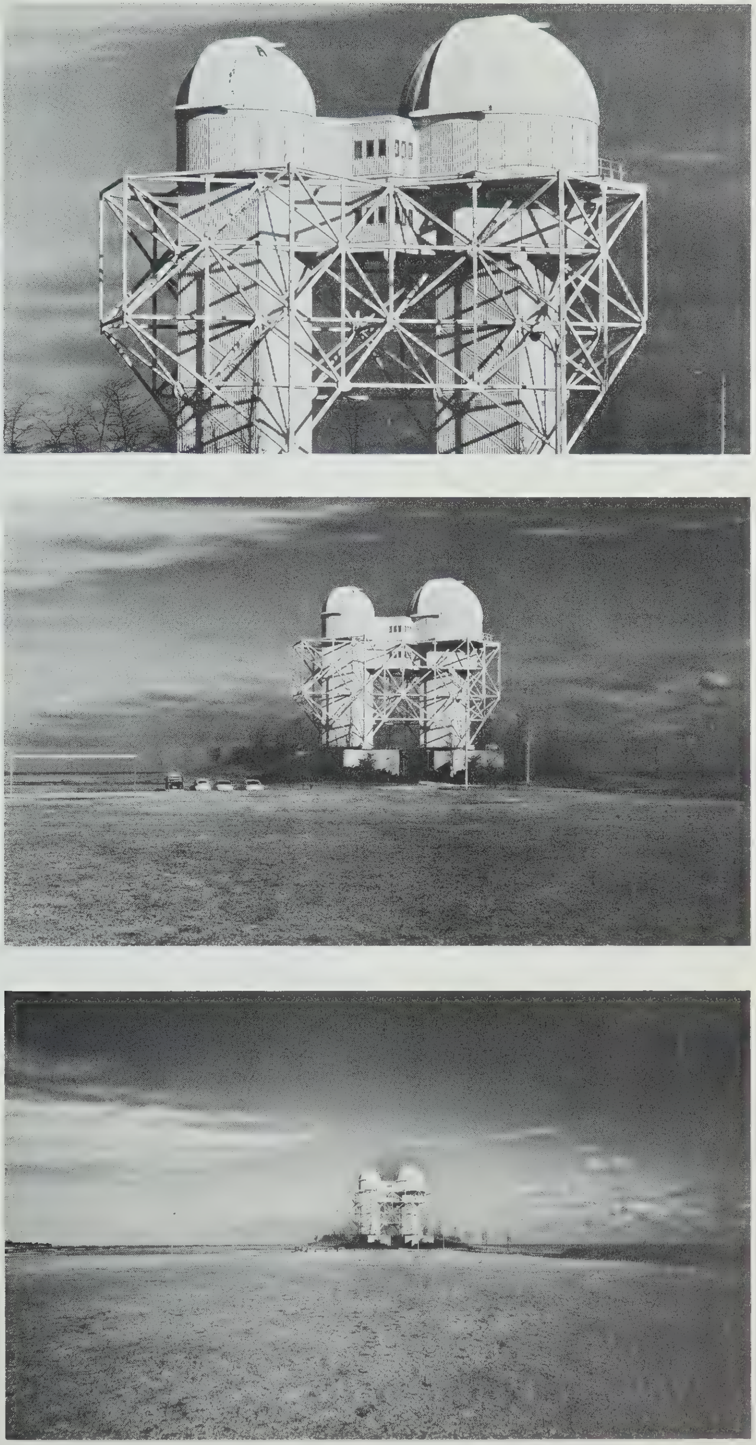
4·20



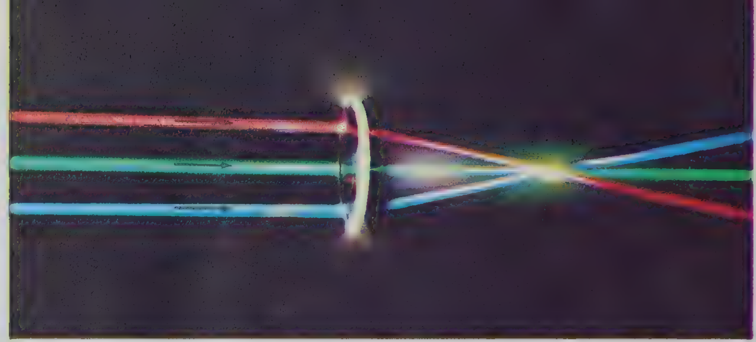
4·21 The focal point of the lens seems to fall in the wing of the butterfly. It is actually in back of the butterfly, since the butterfly is less than one focal length from the lens.

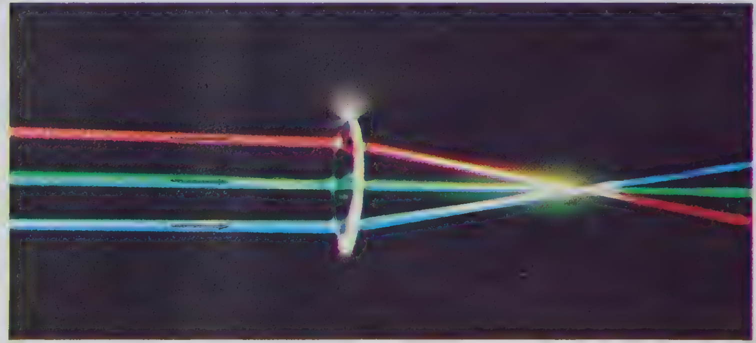
If you get a chance sometime, try casting such an image onto some surface. You'll find that it can't be done. The kind of magnified, right-side-up image that you see when you look at an object through a double-convex lens is a virtual image. It's "imaginary." Your eyes see it through the lens, but the image can't be cast on any other surface.

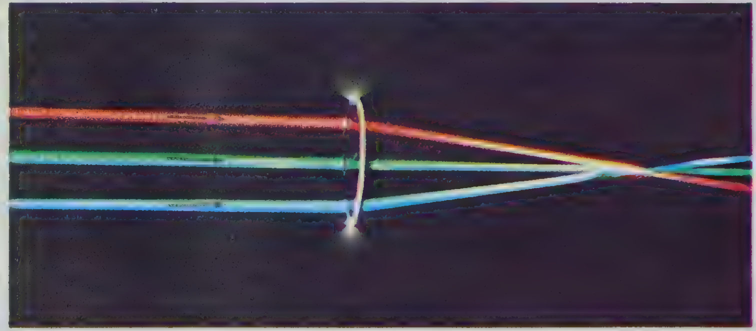
All double-convex lenses don't bend light the same amount



4·22 Lindheimer Astronomical Research Center, Northwestern University, Evanston, Illinois. All three photographs were taken from the same spot. The top photograph was taken through a telephoto lens. The center photograph was taken through a normal lens, and the bottom one through a wide-angle lens.


4·23a


4·23b


4·23c

As you might suspect, the way light is bent by a lens is affected by the material of the lens. Two lenses of the same shape, but of different material, placed at the same distance from an object will not produce identical images. The images will be of different sizes and at different distances from the lenses. Some lens materials bend light more strongly than others.

Remember the refractive index table? It can come in handy if you have two lenses of the same size and shape but made of different materials. The lens with the higher index of refraction will form an image of a certain size closer to itself than will the lens with the lower index of refraction.

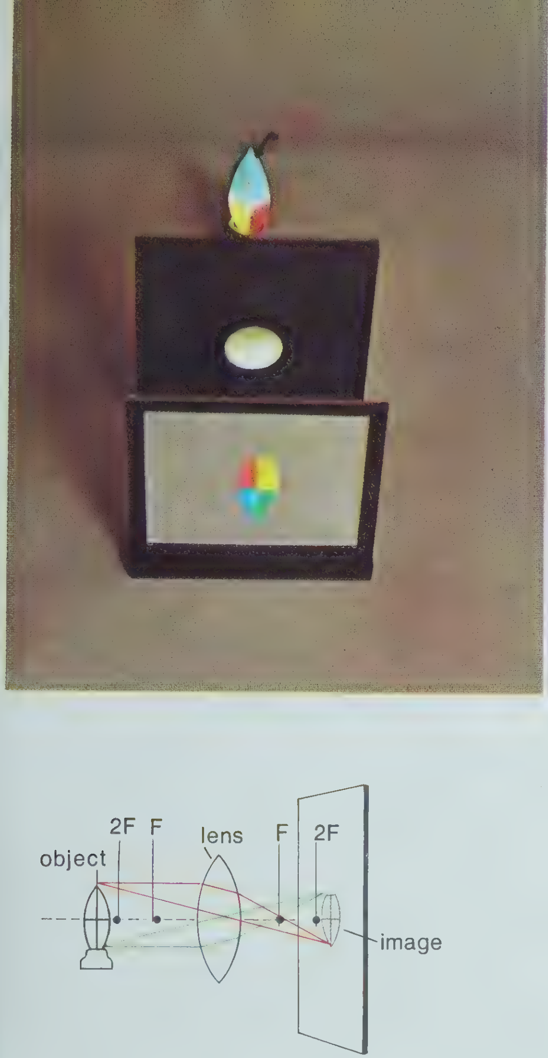
Something else affects the way a lens brings light to a point or creates an image—the degree of curve in its surfaces. In figure 4·23 which lenses have a shorter focal length—the ones more sharply curved ("rounder") or the ones less sharply curved ("flatter")?

Suppose two lenses of the same material are placed at the same distance from identical objects (figures 4·24 and 4·25). Which will give you a larger image—the one with the sharper curve or the one with the flatter curve? For which one will a real image form closer to the lens? If the objects are less than one focal length away, which lens do you think will produce a larger magnified virtual image?

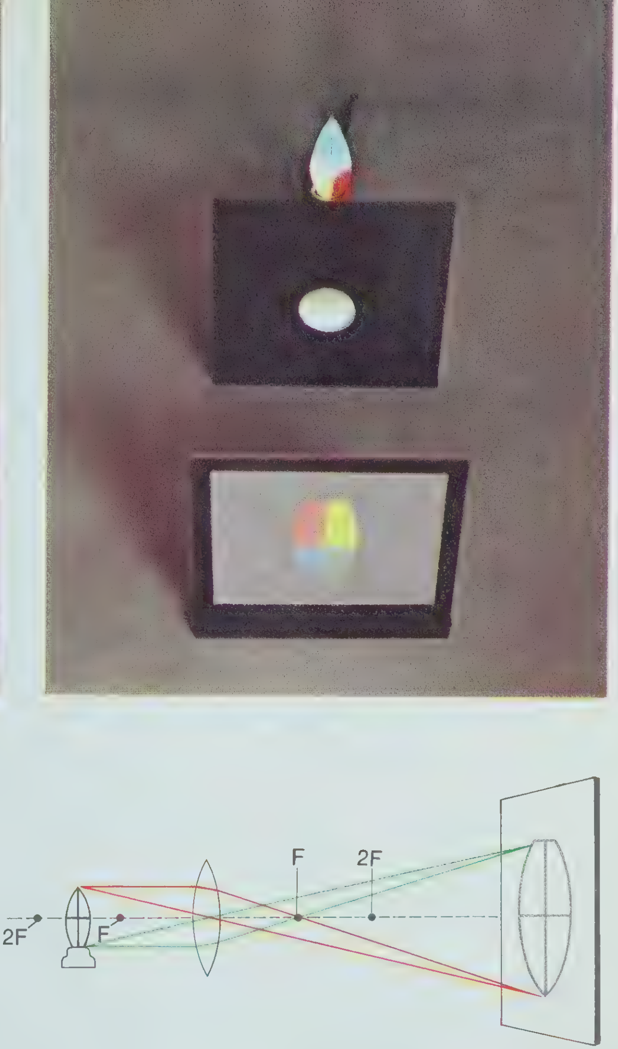
Now you have it—all the basics of double-convex lenses. Pages 86 through 94 are about some uses of these light-benders: eyes, cameras, microscopes, and telescopes.

TEST YOURSELF

1. *What kind of image do you get when a double-convex lens is used as in a camera—real or virtual?*
2. *What kind of image do you get when a double-convex lens is used for a magnifying glass—real or virtual?*



4·24



4·25

3. *What are two differences between a real and a virtual image formed by a double-convex lens?*
4. *Describe the image formed by a double-convex lens in the following situations:*
   a) When the object is very far from the lens.
   b) When the object is two focal lengths from the lens.
   c) When the object is between one and two focal lengths from the lens.
   d) When the object is less than one focal length from the lens.

In all of the cases above, describe the following things about the image that is formed:
a) Its appearance.
b) Its size (larger or smaller than the object).
c) Its approximate location behind the lens if the image is real. For example, is the image one or two focal lengths behind the lens, or somewhere in between?

5. *Draw ray diagrams for each of the cases in question 4.*

Vision and vision correction

Lenses and Your Vision

The lenses in your eyes

To you the most important lenses of all are probably those in your eyes. Without them, the world would look like a big blur.

You can see sharp images instead of blurs because each of your eyes has a double-convex lens. Each of these lenses focuses light from the things around you to form a real image on the back of each eye. The back of each eye, where the image is "caught," is called the retina. The image formed by each lens must always fall exactly on the retina if you are to see clearly.

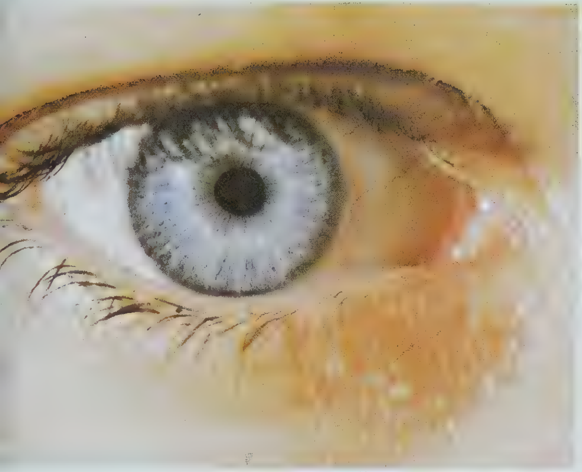
Obviously, the things that you look at are not all at the same distance from your eyes. Yet during most of your life, the distance between the lens in each of your eyes and each retina usually stays the same.

The lenses in your eyes must have some way of adjusting to various distances. In fact, lenses do this by *changing* their curvature. Muscles in each eye push on the lens to make it more curved, and pull on it to flatten it. For focusing on nearby objects, the muscles make the lenses highly curved. For more-distant objects, each lens is made less and less curved.

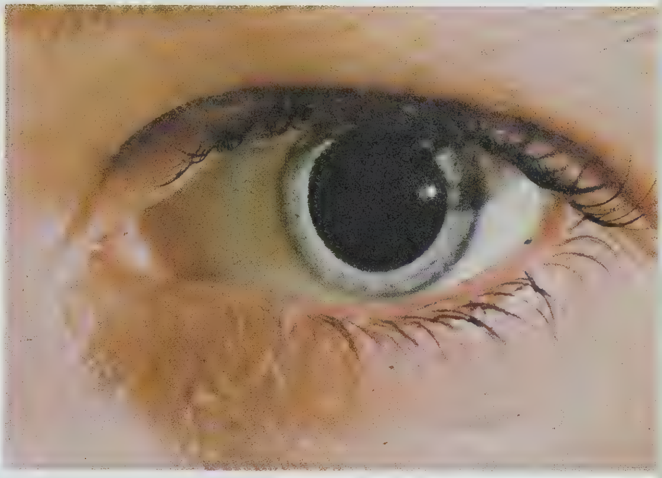
Try changing the thickness of the lens in one of your eyes. First close one eye. Then hold a sheet of paper with some writing on it about 60 centimeters away. Now hold up a finger about halfway between the paper and your eye. Try to see the writing on the paper and the ridges on the skin of your finger clearly at the same time. Can you do it?

When you focus on the paper so you can read it, your finger becomes blurred. Focus on your finger and the writing is blurred. What you were doing when you were switching back and forth between the paper and your finger was causing the muscles in your eye to change the thickness, and therefore the focal length, of the lens in your eye.

Your eyes have another important adjustment. That one is for light intensity. In front of each lens is the iris. It is a very delicate, ring-shaped muscle. The opening in the center of this ring-shaped muscle is called the pupil. It is the dark circle in the center of each of your eyes. In strong light, the iris expands. That is, the



4·26 In bright light the pupil is small.



4·27 In dim light the pupil is enlarged.

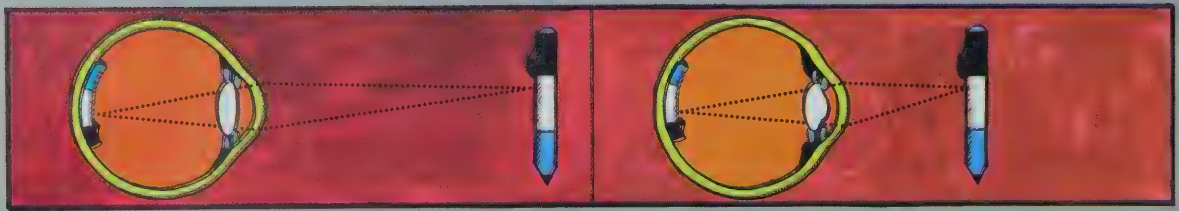
center of this ring-shaped muscle, the pupil, gets smaller. So less light can enter the eye. In dim light, the iris contracts. So the pupil gets larger, and more light can enter the eye.

Out of focus—but not for long

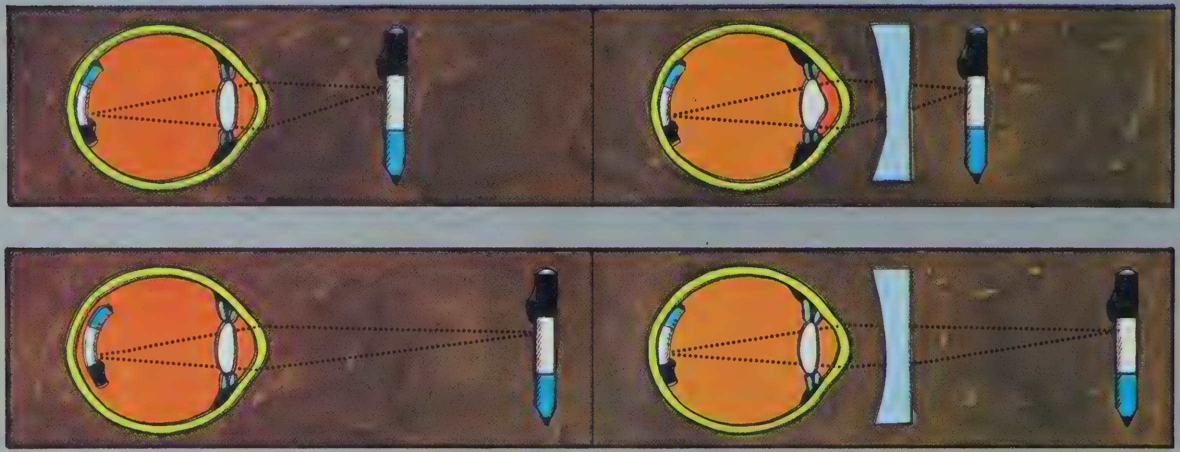
Not everyone can read a printed page at the same distance or see far-off objects with equal clearness. A person can be near-sighted. Such a person can see close objects clearly, but can't make things out at a distance. Or a person can be far-sighted. That is, the person can see distant objects much more clearly than close ones.

Usually, it is the shape of a person's eyeballs that affects how well that person can see things at various distances. A person with good vision has eyes which are almost perfectly round from front to back. Near-sighted eyes are slightly longer from front to back than they are high. And far-sighted eyes are slightly shorter from front to back than they are high.

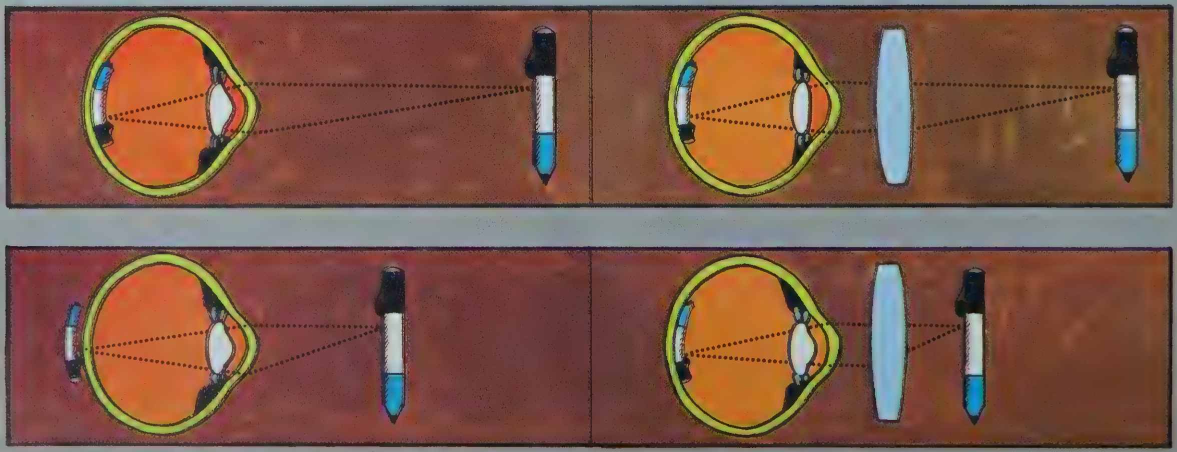
This difference in eye shape changes the distance from the lens to the retina. This change affects the sharpness of the images which fall on each retina. For example, in a far-sighted eye, the retina is too close to the lens. For close-by objects, the lens can't become curved enough to focus a sharp image on the retina. In the near-sighted eye, the retina is too far from the lens. The lens can't become flat enough to focus a sharp image of distant objects.



4·28a The normal eye focused on distant and nearby objects. The image falls exactly on the retina.



4·28b The nearsighted eye attempting to focus on nearby and distant objects, and focusing on those objects with the help of concave eyeglass lenses. Notice in which case the image does not fall on the retina.



4·28c The farsighted eye attempting to focus on distant and nearby objects, and focusing on those objects with the help of convex eyeglass lenses. Notice in which case the image does not fall on the retina.

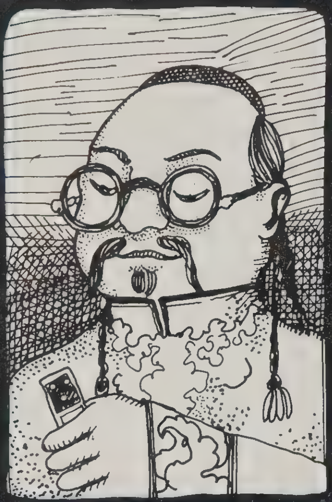
There is another kind of far-sightedness. It is not caused by a too-shortened eyeball. In this case, a person's eyes have normal shape, but the lenses can no longer become convex enough to see close objects clearly. This loss usually happens as people get older. All of these problems have a solution—eyeglasses or contact lenses.

A far-sighted person needs correcting lenses that will make up for natural lenses which are too flat. Slightly convex correcting lenses put in front of the far-sighted person's eyes do the trick. The two kinds of lenses working together—the natural ones and the correcting ones—can give a far-sighted person normal vision. The correcting lenses, of course, have to be individually selected so that they have the right amount of curve for the one person wearing them.

A different kind of lens is needed to correct the eyesight of a near-sighted person. A near-sighted person needs correcting lenses which will spread out light rays before they enter the eyes. Inwardly curved, or *concave,* lenses bend light in this way. So concave lenses working with a near-sighted person's own lenses —which are too convex—will give that person good vision.

Most near-sighted people don't need the light spread as much as it is spread by lenses which are concave on *both* sides. So they wear correcting lenses which are convex on one side and concave on the other. The concave (inwardly curved) side has to have a sharper curve than the convex (outwardly curved) side to produce the light-spreading effect.

SPECTACLES



In 16th-century China, a popular way to keep eyeglasses on was with weighted cords.

At the same time in Europe, one popular kind had a stiff frame and no side pieces.

Ben Franklin is credited with the invention of split lenses, now called bifocals.

In the 19th century, people who didn't want to keep eyeglasses on all the time used lorgnettes.

Now contact lenses are common. They float on each eye on a layer of tears.

Many people still like to wear eyeglasses. The styles are surprisingly similar to older ones.

ON YOUR OWN

How strong are your glasses?

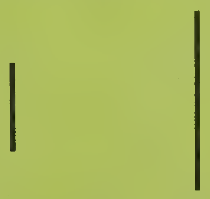
Eye doctors have a system of describing the strength of eyeglass lenses. The unit of strength is the *diopter*. The more diopters a lens has, the stronger it is.

To figure out how many diopters a convex lens has, take its focal length in meters (or part of a meter) and divide it into 1. That is,

$$\text{diopters} = \frac{1}{\text{focal length in meters}}$$

Suppose the focal length of a lens in a pair of glasses for far-sightedness is 0.5 meter. One divided by 0.5 is 2. So the lens is 2 diopters strong.

It's more difficult to find the strength of a convex-concave lens, the kind used to correct near-sightedness. Since a concave lens spreads out light instead of gathering it to a point, such a lens does not have a real focal point. But there is a distance measurement you can use that is related to the sharpness of the inward curve of such a lens.



One of the two lines on this page is twice the length of the other. Put a convex-concave lens over the longer line with the concave side facing you. Then stand back and look at it so that you can see the long line through the lens and the short one outside the lens. Keep moving the lens away from the page until the long line, seen through the lens, looks the same length as the short one outside the lens. Measure the distance from the page to the lens. You can use this distance as the focal length in the formula for finding the strength of a convex-concave lens in diopters.

There is one catch to this method. You will find that the distance you hold the lens from your eyes changes your measurement. It's important that you find the spot where both lines look the same length when the distance from the page to the lens is the same as the distance from the lens to your eyes.

When speaking about how strong lenses are, eye doctors may say that one lens has +2.5 diopters and another has –1.7 diopters. If the lens is convex (for far-sightedness), eye doctors say it is *plus* so many diopters. If it's convex-concave (for near-sightedness), it's *minus* so many diopters.

Most people who wear glasses need lenses of not more than about plus 2 or 3 diopters or minus 2 or 3 diopters to correct their vision. Some people, though, need lenses of as many as 10 diopters.

ON YOUR OWN

Through the water glass

All you need for this activity is a glass of water. The glass should be clear, so should the water.

Hold the glass in front of one eye as you look at yourself in the mirror. Or hold it close in front of a friend's face. Does yours or your friend's eye look the same size as usual when you look at it through the water glass? Why not?

Then have your friend move away from you about half-way across the room. Close one eye. Hold the water glass about 20 cm from your other eye. Look at your friend through it. Have your friend lift his or her left arm. On which side do you see the lifted arm through the water glass? Why?

Other Seeing Aids: Microscopes and Telescopes

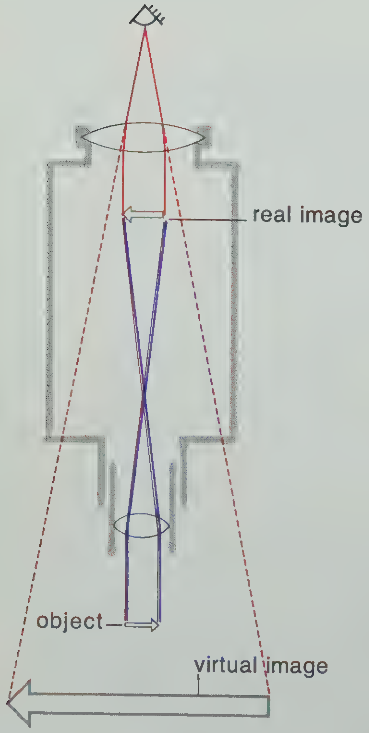
The use of two double-convex lenses for magnification

A microscope or telescope increases the seeing power of your own eyes many times. When you look through a microscope or a telescope, you are looking at objects through two double-convex lenses (plus your own eye's lens).

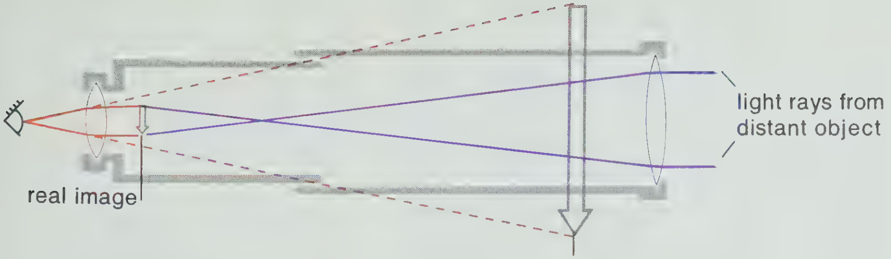
First, the basic ideas behind a microscope: Suppose that you hold a double-convex lens with a very short focal length a bit farther from a small object than one focal length. You will see an enlarged, inverted, real image of the object. If the object gives off enough light, you can prove a real image exists where a diagram says it should by placing a card there, so that you can see the image. But a real image exists at a particular place whether or not it is bright enough to show up on a card. To say that a real image exists somewhere means that light rays from the same spot on the object come together there. And this image can be refracted, reflected, or just looked at with your eyes or through another lens—just as you would look at an object.

Now, suppose you could look at that real image through another double-convex lens. Make this second double-convex lens less sharply curved than the first. And put it *almost* one focal length from the real image produced by the first lens. Remember that a double-convex lens less than one focal length away from something acts like a simple magnifying glass. If you look through this second lens at the image produced by the first lens you should see an enlarged, *upright* image of the first *upside-down* image. But the real, inverted image itself was larger than the object. So you've greatly magnified the object by looking at it through both lenses. Make two such lenses part of a container like the one in figure 4·30 and you have a microscope.

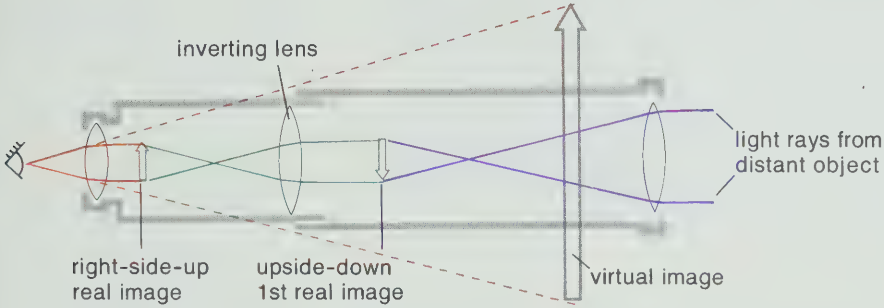
Now the basics of a telescope or binoculars: In this case you start with a double-convex lens with a long focal length, which you use to get a real image of a distant object. The object is a long way off compared to the focal length of the lens. So the real image will fall one focal length from the lens. Since the image is real, it will be inverted.



4·30 The microscope



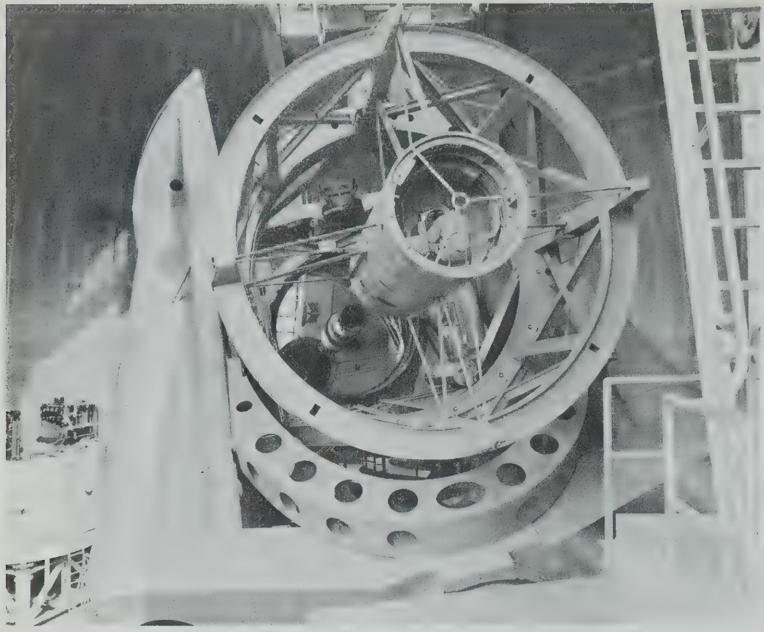
4·31 Simple telescope



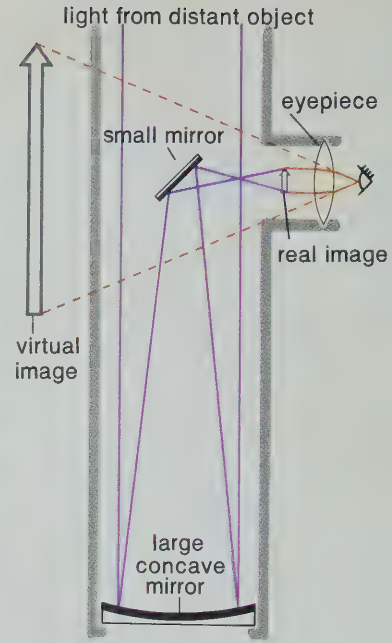
4·32 Telescope with inverting lens

Then suppose you put a second double-convex lens again *almost* one focal length away from the real image formed by the first lens. This second lens will again act as a simple magnifying glass. It will magnify the real image focused by the first lens. Put two double-convex lenses in this arrangement in a tube and you have a simple telescope (figure 4·31). Have two such tubes attached to each other side by side and presto—binoculars.

The images you can see through both the microscope and the telescope diagrammed here are upside-down images. They will look upside down when compared to the object. This usually doesn't bother an astronomer looking at the stars through his telescope or the biologist looking at bacteria through his microscope. But such results might confuse someone using a simple telescope to watch a distant ship, or binoculars to watch a ball game. So telescopes and binoculars, which are used to see things right-side-up, usually have a third convex lens. This third lens is put between the first two lenses and is called the inverting lens. The inverting lens turns the real (inverted) image produced by the first lens into an upright image (figure 4·32).



4·33 The Hale telescope at Palomar Observatory in California is a Newtonian type reflecting telescope. It is a large metal tube with an open end pointing skyward. There is a 500-cm diameter mirror at the other end of the tube.



The eyepiece of the telescope is at the side of the tube at a right angle with the tube. Light rays entering the tube are reflected by the large mirror into the small mirror. The small mirror reflects the image into the eyepiece.

ON YOUR OWN

Lens combinations for a microscope and a telescope

You will need several double-convex lenses. Magnifying lenses, each of a different strength, can work. One should have a focal length that is three or four times as long as the focal length of the other. That is, one should be much more sharply curved than the other.

Hold the lenses in front of one eye so that they work as a microscope when you look at some small object close by. Then try to get the lenses to work as a telescope.

HINT: For both the telescope and the microscope, you'll get much better results if the weaker lens is noticeably larger in diameter than the stronger lens.

The lenses in microscopes and telescopes that you can buy have usually been cut down from much larger lenses. The edges have been cut away and just the centers of the lenses are used. From your experiences with lenses, why do you think this is helpful?

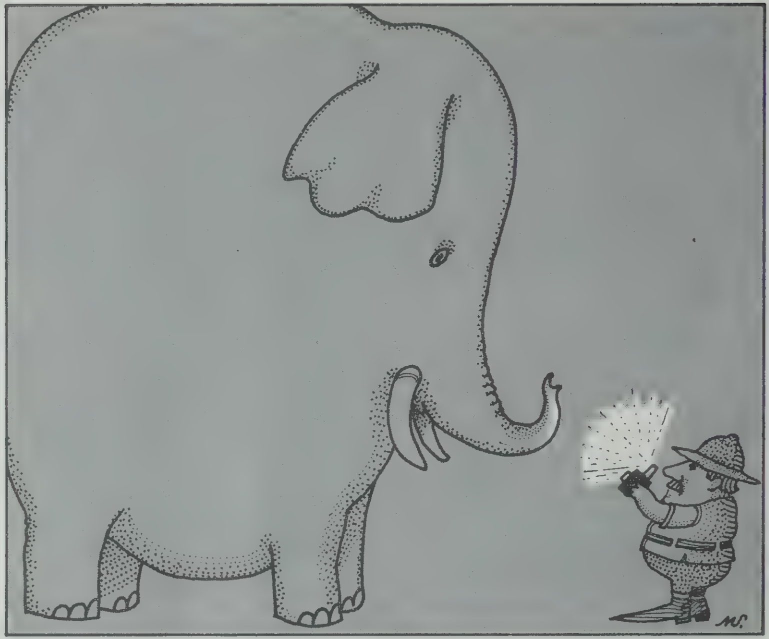
Chapter 5: The Brightness of Light

5

If you look too closely at a floodlight like the one in the photograph, your eyes will hurt. You may have experienced such a reaction.

There is a quality of light that determines how much it affects eyes, photographic film, or other light-sensitive things. You may think of this quality as the amount of light, or the brightness or dimness of light.

This chapter will deal with a mental model for this quality of light and some ways this mental model is useful in everyday life. And at the end of the chapter is the last installment to the what-is-light question.



5·1

Perhaps at one time or another you have seen people using a flashbulb when taking a photo of a large or distant object—such as a player on a baseball field or a building. It's usually a waste of a flashbulb. The flash from the light bulb is very intense close up. But it's too weak to light up an object at any great distance.

You can easily get a general idea of the brightness of light. First, look at an unshaded light bulb. Notice that light goes out from it in all directions. If one side of the bulb is blocked, light will still spread out from the unblocked side. You can see how the brightness of the light changes as the light spreads out. The light is most intense right near the bulb, but decreases in intensity as it spreads out.

The handiest instrument to measure the way the intensity of light changes with distance from a light source is a *light meter.* A light meter has been used in figure 5·2.

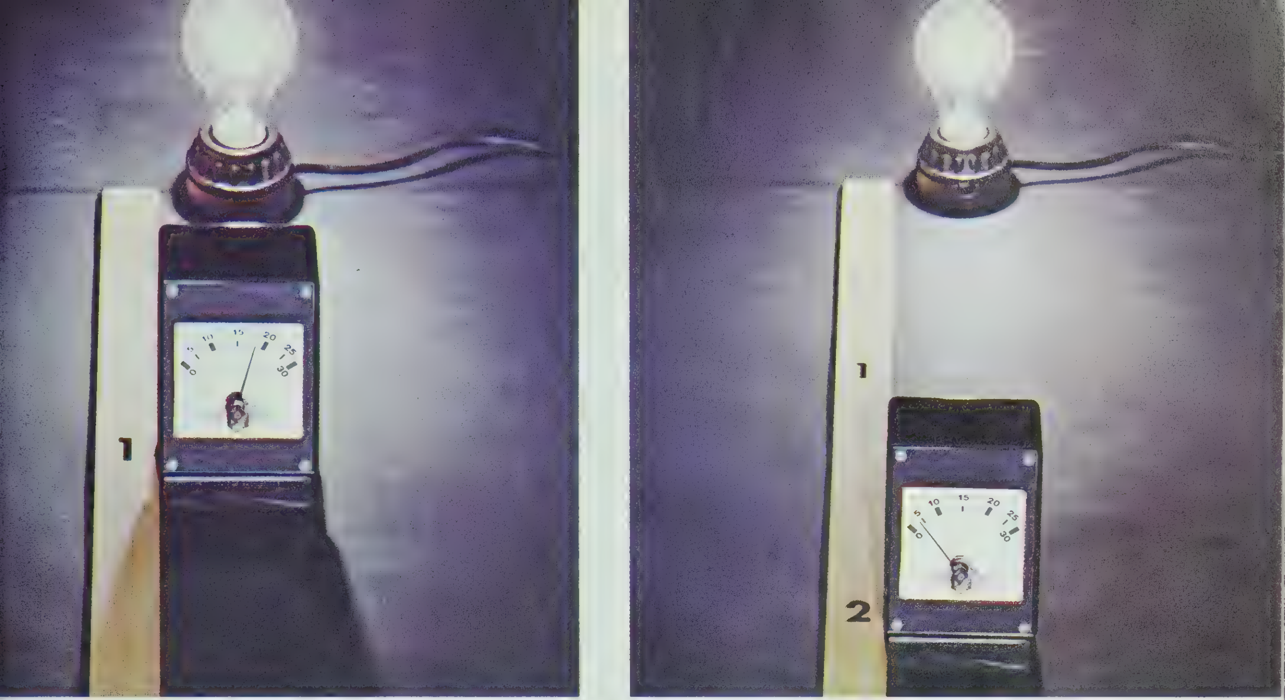
Notice what happens to the meter reading when the distance between the light meter and the light bulb increases. Are these results what you expected? (By the way, this light meter is picking up light only from this single bulb. There is no other light in the room and the dull black walls are nonreflective.)

The intensity of the light decreases as distance from the light bulb increases. Notice also that the light intensity seems to drop off faster than the distance increases.

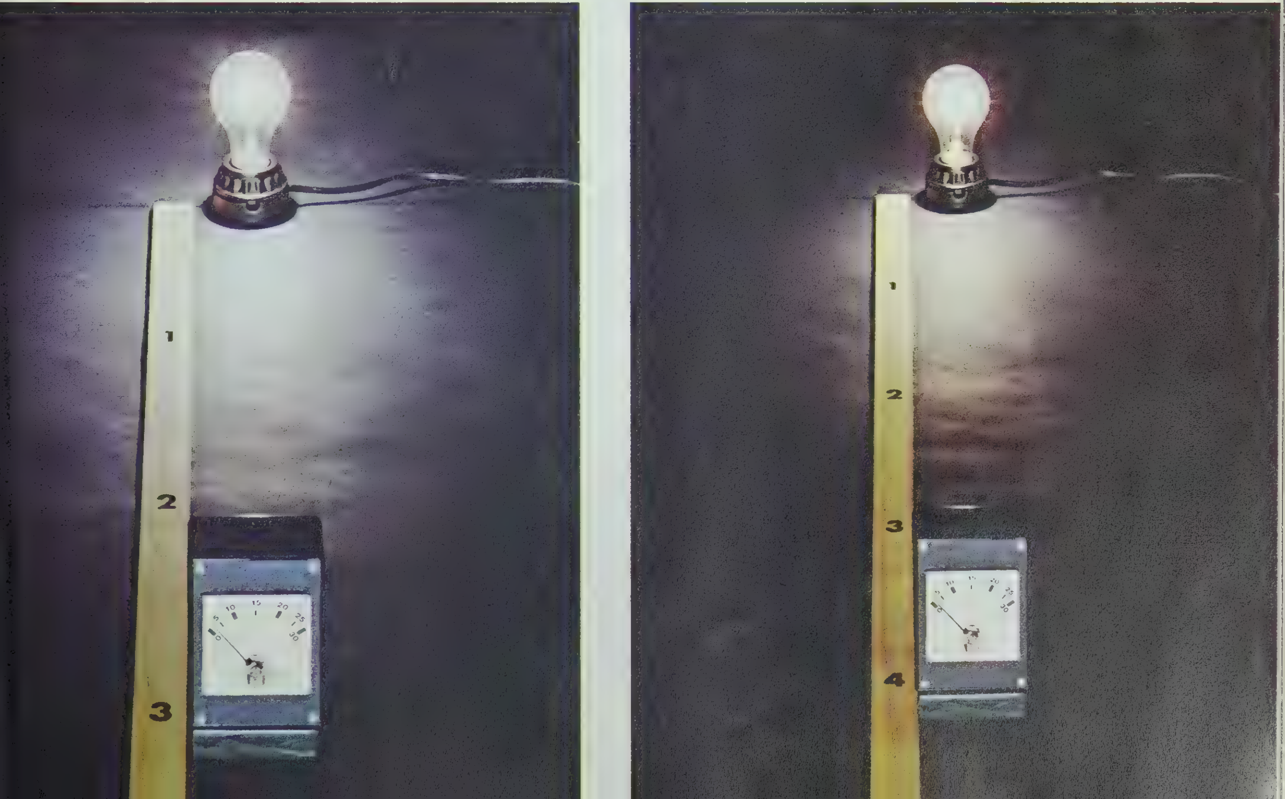
For each doubling of the distance, the number of units of intensity drops by a factor of four. For each threefold increase in distance, the intensity drops by a factor of nine. And for each fourfold increase in distance, the intensity drops by a factor of sixteen. So there is a definite mathematical pattern. You can use proportions to show it.

Table 2 Ideal Relationships of Distance and Light Intensity

Intensity at Near Point	is to	Intensity at Far Point	as	(Distance to Far Point)^2	is to	(Distance to Near Point)^2
1	is to	$\frac{1}{4}$	as	$(2)^2$	is to	1
1	is to	$\frac{1}{9}$	as	$(3)^2$	is to	1
1	is to	$\frac{1}{16}$	as	$(4)^2$	is to	1
18	is to	$4\frac{1}{2}$	as	$(2)^2$	is to	1
18	is to	2	as	$(3)^2$	is to	1
18	is to	$1\frac{1}{10}$	as	$(4)^2$	is to	1



5·2 Notice how quickly the meter readings fall as the distance between the meter and the light bulb increases.

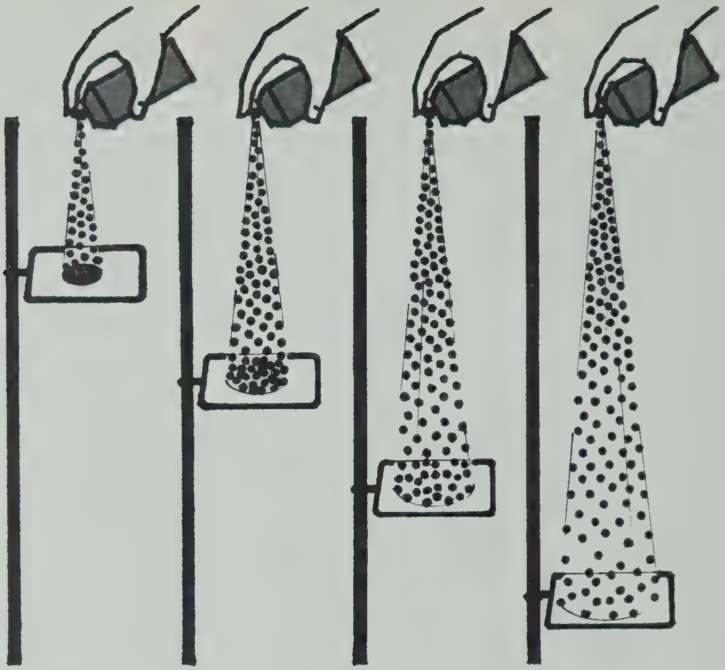


A spray of light

In studying light intensity, or brightness, it's helpful to have a model that behaves the same as light leaving a light source. You need a source of something that starts at one point and spreads out evenly. It also has to be something that you can see and measure more easily than light beams.

A useful model is no farther away than the nearest paint shop. Consider the simple paint sprayer. It produces paint in straight lines through a wide angle. What is more, if you spray a surface far enough from the nozzle, the paint falls in visible droplets.

Figure 5·3 shows how to measure the "intensity" of the spray. In a special room where no one minds getting paint everywhere, we set up the sprayer as shown and attach white cards at various heights to a pole. By estimating the dots that fall on each card during a standard one-second burst, we will have a rough measure of paint "intensity."



5·3

We find that, if we spray for one second (measured with a stop watch), we can get individual dots on the second card down. If we spray more briefly than that, it is hard to measure the time accurately. If we spray very much longer, there are too many dots. And they blend in with each other.

Notice that the spray spreads out evenly from the nozzle of the sprayer. In other words, the same amount of paint that starts out at a tiny nozzle spreads out into a larger and larger area. Note also the shape of the sprayed area.

How does this shape compare to the shape of a projector beam cast on a card (figure 5·4)? In each case, how does the intensity at the source (nozzle or projector bulb) compare with the intensity at the target (the card)?

It looks like the paint sprayer is a handy model for light intensity. Light spreads from a lamp and strikes a surface, just as the paint drops spread and hit the cards. If the surface happens to be that of a sensitive light meter, the meter can react to the "drops" of light hitting its surface. It can measure them as if it were counting drops of spray paint.

The light meter, though, gives readings on a continuous scale. If light does come in drops, they are apparently too small to be counted individually by even the most sensitive meter.

TEST YOURSELF

1. *Suppose it's a very cloudy day. Why would it be wasteful to use a flashbulb on your camera to snap a photo of a building a block away?*
2. *Does a light-meter reading get larger or smaller as it is moved away from a light source? Why?*
3. *A light meter is 20 centimeters from a light bulb. The meter reads 48 intensity units. At 40 centimeters from the bulb, what should the reading be if no other light is present?*
4. *A light meter is 60 centimeters from a light bulb. The meter reads 20 intensity units. What should it read at 20 centimeters if no other light is present?*

5·4

ON YOUR OWN

Getting dimmer

Hold an open book about 90 cm from a lamp or light bulb. Have no other light in the room. Notice how bright the page is. Then move the book to 45 cm from the lamp. Does the page seem to get only twice as bright as before? Try various other distances. For example, what does the page look like at 180 cm from the lamp?

Controls for light entering a camera

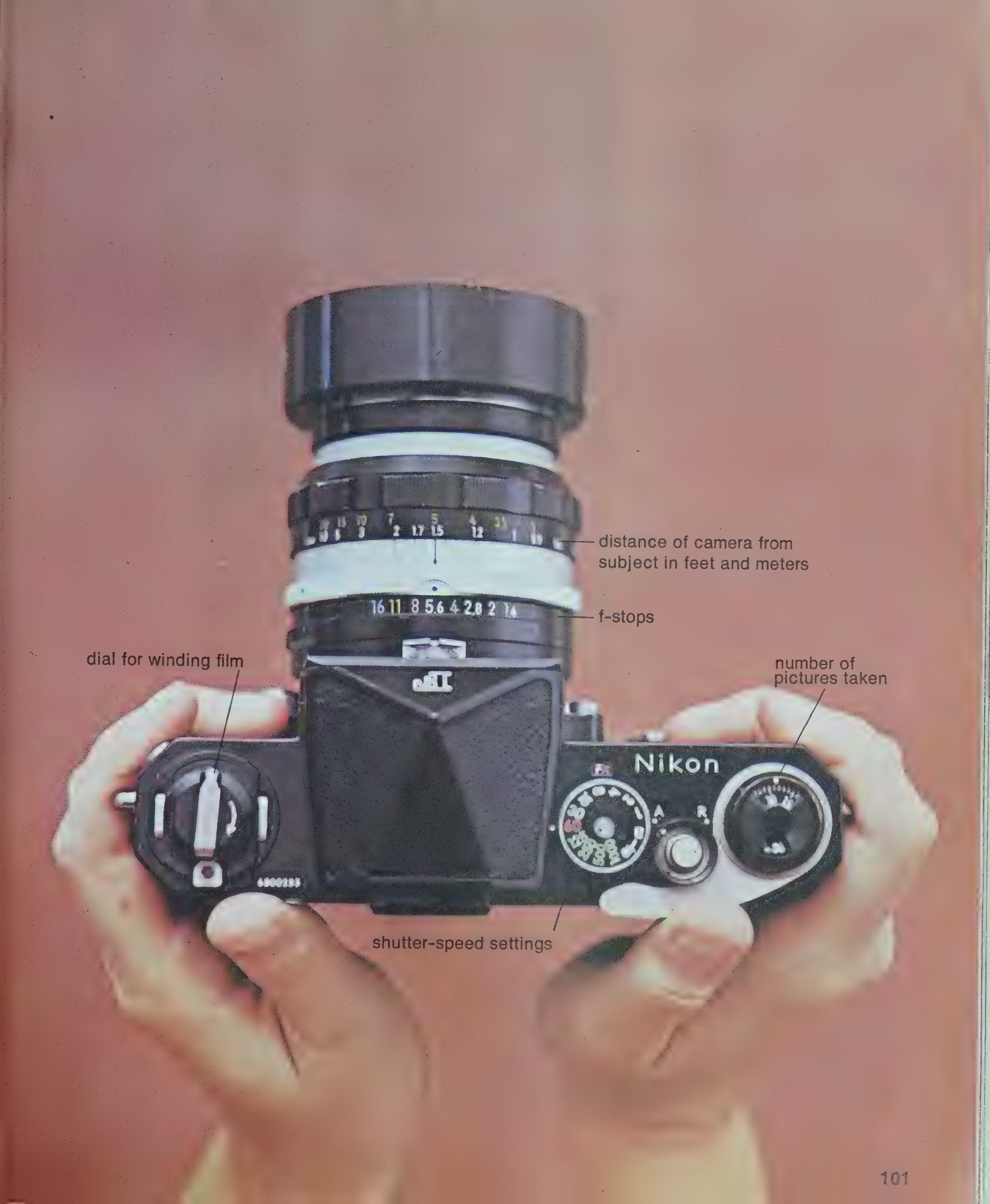
A Photographer at Work

Two things are important in getting a good photograph. First, the photograph must be in focus. That is, a clear image of a scene or object must form on the light-sensitive film at the back of the camera. For this to happen, the lens at the front of the camera must be set at the proper distance from the film. The photographer adjusts the lens position in the camera for this purpose. The second requirement for a good photo is the right amount of light. To meet this need, the intensity of the light entering the camera must be controlled.

A photographer can control intensity by adjusting the size of the light opening of the camera. The size of the light opening in front of the lens is controlled by the *shutter.* The shutter opens very briefly to let light into the camera as the picture is "snapped." If the shutter is set to uncover the whole lens, the maximum amount of light will enter the camera. If the light coming toward the camera is very bright, this large an opening might cause an overexposed negative. The result is a photo that looks pale and lacks detail. On the other hand, too small an opening will result in an underexposed negative, and a photo that is very dark or even totally black.

To set the size of the camera opening properly, the photographer selects one of a group of numbers called *f-stops.* These f-stop numbers are printed on a ring around the lens-shutter part of the camera. A typical series of f-stops is 2.8, 4, 5.6, 8, 11, and 16.

The photographer also selects the length of time the shutter stays open. This setting of the shutter-speed depends on the intensity of the light coming toward the camera. If the light is very bright, the briefest setting should be used. (Remember how a long spray of the paint sprayer left too many dots of paint?) If the light is *not* very bright, the shutter must stay open longer, to let more light react with the film. The shutter-speed settings are printed on the camera near the f-stop settings. A typical range is *30, 60, 125,* and *250.*

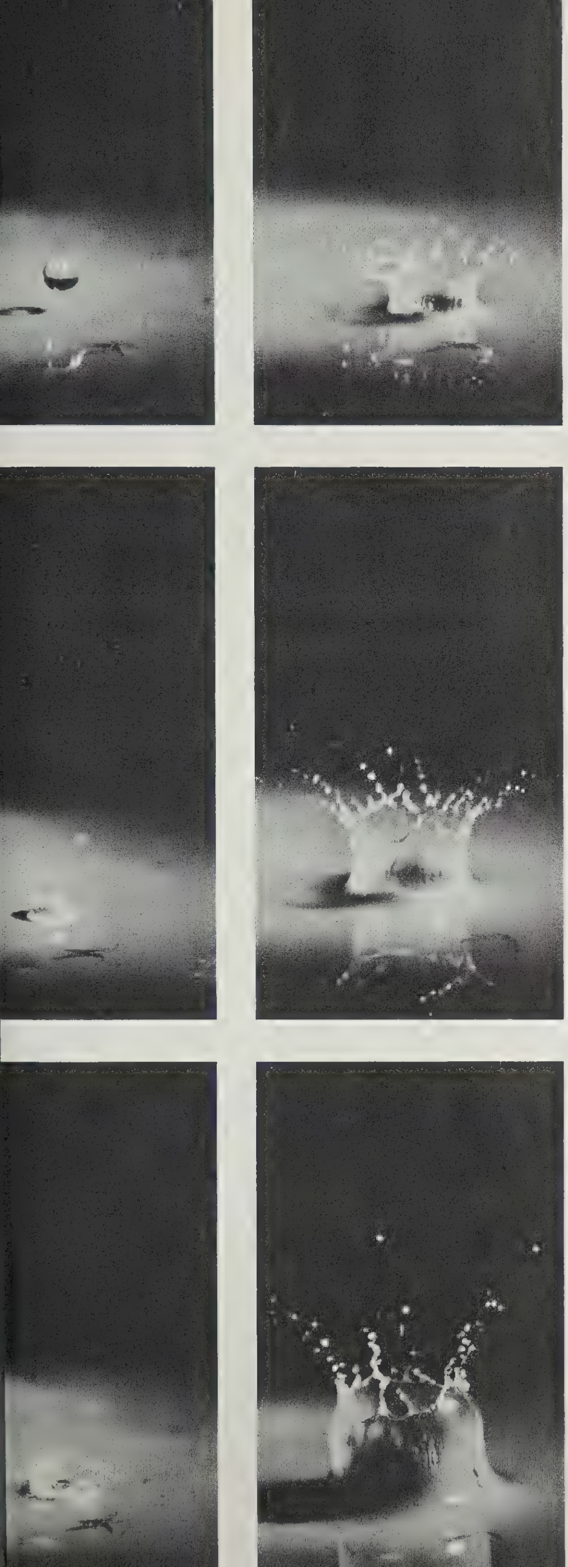

distance of camera from subject in feet and meters
f-stops
dial for winding film
number of pictures taken
Nikon
shutter-speed settings

These numbers stand for fractions. For example, 125 means *1/125th of a second.* Some cameras give speeds as slow as *1* second. Some, used in scientific work, expose the film for as little as 1/1,000 of a second. Many cameras also have an adjustment so that the shutter can be kept open by hand as long as the photographer wants.

To measure the intensity of light for the selection of f-stop and shutter-speed, the photographer often uses a light meter. Light that strikes a sensitive material in the meter causes a tiny electrical signal to go to the indicator needle. The needle then swings across the scale and stops at some value. This meter reading enables the photographer to adjust the camera with precision.

Because distance from a light source affects the intensity of the light, the photographer also controls this distance. The light that exposes the film is the light reflected by the subject. So the photographer notes the distance from subject to camera. If the subject is close and bright, the photographer will need to lower the time the shutter stays open, or make the camera opening smaller, or do both.

Other sources of light near the subject must also be carefully placed. In a studio situation, when an artificial light such as a floodlight is used, the photographer will place the light to give the best results. A light too close to a light-colored subject, for example, can be too intense and erase the details of the subject. A light too far away, on the other hand, has too little intensity at the subject. The simple rules of light intensity help the photographer determine just how far away the light sources should be.



5·7 Raindrop falling in water. This series of pictures was taken in less than 0.1 second.

ON YOUR OWN

In the dark

Experiment with the effect flashbulbs have on how well your snapshots turn out.

Take a series of photographs of something in a dim room, each time at a different distance from that object. For example, start at several meters from the object. And end up at the other side of the room.

Use the same kind of flashbulb each time. Don't change anything else, except the focus on your camera. On some cameras you don't even have to adjust the focus.

Study the results. How effective was the flashbulb at the various distances?

What Is Light?
Part 5

A meeting of the particle and waves theories of light

In this unit you have used three different ways of describing light. You used pencil lines to represent imaginary light rays. You talked about these straight rays moving through space, bouncing off walls, spreading out onto a card or a wall, and coming together to produce images.

You have also treated light as imaginary particles. You considered particles bouncing off walls, particles striking the cells of the eye, particles striking a light meter, and particles spreading out to cause a decrease in brightness.

And third, you used the idea of waves of light moving from one point to another, passing through pinholes and spreading apart, meeting one another and producing light and dark bands, and being bent as they move across boundaries of matter.

But what is light *really?* Is it particles? Or is it waves? Or is it rays? It could not be all three, could it? Or could it? What does it really mean to say that light *is* waves, or light *is* particles? Actually, the question is not really about light. Light is light. The question is, how are we to *understand* light?

Let's go back to the turn of the century when light—and what it is—seemed to be under control. The wave theory, aided by experimental results, described fairly well all the evidence then available about the nature of light. Light was a series of waves.

It was a new century, though, and new scientists were coming on the scene. One was Albert Einstein. The special gift of young Einstein—and old Einstein as well—was his inability to see things the way he was told to see them. Instead, he thought carefully about his experiences and those of others. And then he thought carefully about his thoughts. And then—when he thought about his thoughts about his thoughts—he sometimes began to consider them "very interesting." But while Einstein thought, other scientists performed experiments, which were also "very interesting."

In the very last years of the 1800's, scientists had already gotten some puzzling results when measuring light given off by heated objects. The results came out in a complicated form that had no ready explanation. Scientists everywhere pored over their wave-theory notes to find formulas that would fit the results. In a few cases they came close, but not close enough.

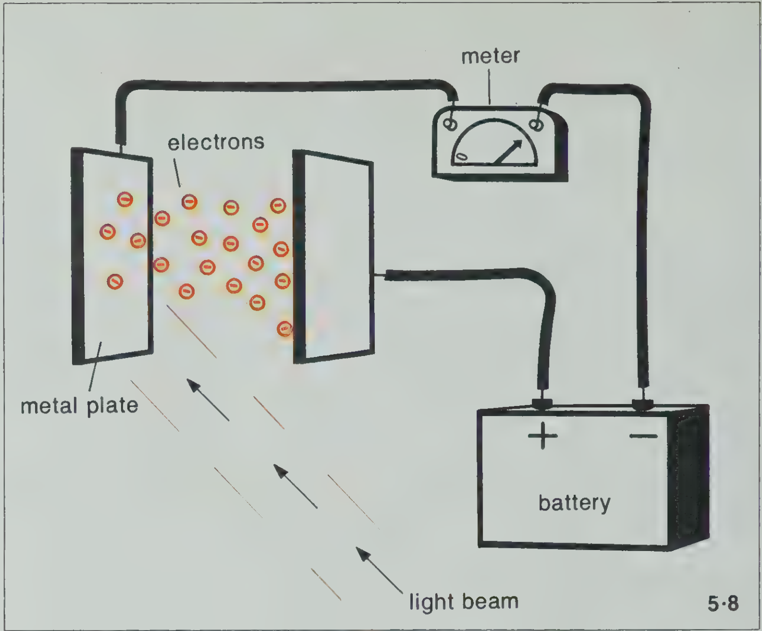
Finally, in the year 1900, a German scientist, Max Planck, came up with a near-perfect explanation. But Planck himself was surprised by his conclusions. They pointed toward the existence of particles of light energy. He tried hard and long to disprove himself and bring back the old understanding of light as waves. In the end, though, the new theory stood.

What Planck saw was a special way in which heated objects give off light. If an object is heated enough it will give off light. But it seemed to Planck that the light was not given off in a steady flow, as in waves. Instead, the light energy seemed to be given off a certain amount at a time—in "packets." The idea of "packets" of light was truly revolutionary. Only when his idea was supported by results from very refined experiments over the next 50 years, was it accepted as an accurate explanation of the observed facts.

At first, however, most scientists, including Planck, avoided turning this idea of "packets" of light into a whole new theory of light, a theory which seemed so similar to the old particle theory. Scientists would admit only that heated objects seemed to give off and receive light energy in packets.

It took still another puzzle to shake loose the old and bring on the new. The new puzzle was called the *photo-electric effect.*

In the experiment that produced the photo-electric effect, light was used to bounce particles of matter off a metal plate. The particles that came off were the tiny ones that carry the negative electric charge of matter. These tiny particles are *electrons.* A movement of electrons can produce an electric current. This current can be accurately detected with meters.



5·8

The setup of the experiment, in a very simplified form, is shown in figure 5·8. As soon as the light beam began to knock electrons off the metal target, the meter showed the number of electrons that were being affected.

The experiment was done many times, with very precise methods and measurements. It had undeniable, yet, at the time, surprising results.

First, the experimenters measured the energy of motion of the electrons that were bounced off. From the start of the experiment, the energy of the electrons remained at a certain value. Increasing the intensity of the light did not increase the speed of the bounced-off electrons. As long as the same color of light was used, no matter how intense the light, the energy of the electrons started and stayed at the same characteristic value.

Second, the experimenters tried bombarding the metal target with light from all different parts of the spectrum. These experiments indicated that only light toward the blue end of the spectrum would work well.

Both of these results caused physicists to scratch their heads.

To begin with, the fact that the speed of the bounced-off electrons did not increase as the intensity of bombarding light was increased went directly against the wave theory. Apparently electrons did not "soak up" a flow of energy as they would from waves.

Einstein reasoned that the electrons must, instead, gulp energy in definite quantities. It apparently takes a certain size packet of light energy to budge an electron. Until a packet of light energy of the right size arrives within range of an electron, the electron won't leave the metal target. If many energy packets of the right size arrive, many electrons are freed. But if the packets are too small, not an electron will leave—no matter how many packets of energy are available.

These theoretical packets of light were another experimental appearance of the light particles that Planck had theorized. In Einstein's writings, these packets are called *photons.*

In the photon theory, photons of red light have very little energy. Photons of green light have more. And photons of blue-violet light have the most energy in the visible spectrum. It's because of their high energy, that photons of blue and violet light give the best results in the photo-electric experiment. Each of the photons has enough energy to budge and to speed up an individual electron.

So there you have the photon model—light as particles. But that doesn't close the book on the wave theory. There are many situations in which a wave model of light is much more helpful. For example, this is the case for light refraction and interference.

Physicists have developed complicated mathematical formulas for light behavior. But the formulas don't really give a *picture* of light. In order to make the formula correspond to a familiar model, you would have to leave out some of the finer points. Depending on what you left out, what remained might be a formula for particle behavior. Or it might resemble the formulas for wave behavior. Use whichever suits the situation best.

Magic light that
"zaps" holes in steel
may take us to Mars,
aid blind people,
and provide unlimited TV

Laser: Beam of the Future

As the 1960's dawned, a mysterious new force was created that conjured up images of "death rays," power to rival the sun's, and earth-boring guns to match Superman's ability. The sheer power of the *laser*—especially the newer models—is awesome. For a brief instant, a laser can generate enough power to supply the electricity for a city of a million people—hundreds of millions of watts.

Yet that same laser beam, properly controlled, now is being used to "weld" loose retinas inside the human eye and even to perform "microsurgery" on a single living cell.

In potential impact on the world, in fact, the laser can be compared only with the development of the transistor, which burst upon the world of electronics and technology in the 1950's. Lasers create the sharpest, most intense, purest light ever known. And their versatility ranges from drilling a hole of one one-thousandth of an inch in a tiny diamond to vaporizing any substance on Earth.

The future of lasers still is to be determined. A laser beam can —theoretically, so far—heat a pot of coffee a thousand miles away or transmit on a single beam every television, radio, and telephone transmission in the world simultaneously.

Some day lasers will help create book-sized electronic computers, and wall-sized home television screens or even trigger a controlled thermonuclear power plant to harness for mankind the cosmic energy that lights the sun and other stars.

Yet for all this capability a laser is a relatively simple piece of equipment. Hobbyists have built them at home and some electronics firms are now selling them to schools for just a few hundred dollars.

How lasers work

If a light wave from a conventional light bulb could be heard, it would sound like static on a radio. It would be a combination of frequencies ranging from low bass to high treble. If the light from a laser could be heard, it would have the pure tone of a perfect musical note. That's because laser light, unlike sunlight or lamplight, is all of one wavelength. The light waves all move in the same

Adapted from "Laser: The Beam of the Future" by Richard J. Pothier from *Chicago Daily News* (February 10, 1970). Reprinted by permission of the author.

direction and are all "in phase." They're "in step" so that one reinforces the next, like voices singing in a choir.

An artificial ruby forms the core of a typical laser. The ruby is about the size and shape of a cigaret. Both ends of the crystal are ground and polished perfectly flat. One end of the ruby is silvered and the other is only partly silvered.

Chemically, rubies contain particles that are "excited" when ordinary light of high intensity strikes them. Ruby lasers include a powerful flashtube to supply that ordinary light. "Lasing," the accepted verb for what happens, occurs when these excited particles emit a single "packet" of light by shooting it out in a direction exactly parallel to the ruby crystal's long axis.

The particles of matter also emit other light "packets" in other directions. But they pass through the nonsilvered sides of the ruby instantly and thus are lost.

When one packet of light hits the fully silvered end of the ruby, it is reflected back and strikes the other end. But before it does, it hits other particles of matter, which then emit other packets of light. The beam builds up as it picks up new light packets. It's a bit like a column of marching men, picking up stragglers as they march up and down a long avenue. But only parallel light packets are added. Any light not moving in the exactly back-and-forth direction between the two mirrored ends of the ruby is lost almost instantly through the sides of the ruby.

Soon, the light waves build up until they're powerful enough to flash out of the less-silvered end of the ruby, a narrow, parallel, concentrated, powerful beam of light.

After several million back-and-forth bounces inside the ruby crystal, all the out-of-step light waves are discarded and "lasing" begins. Typical laser light vibrates 500 trillion times a second. But the vibrations are perfectly in phase with each other.

The effect might be compared to ripples on a pond. Ordinary light is a jumble of frequencies and phases, something like the effect you'd see if you dropped a million tiny pebbles into a still pond. Laser light is "coherent," the technical term for its parallel, all-in-step nature. A single large stone dropped in that same pond

5·9 Holes are being drilled in a metal plate by a laser beam. The lens focuses the beam so it hits the exact point where the hole is to be drilled.

would produce a series of regular, reinforcing ripples.

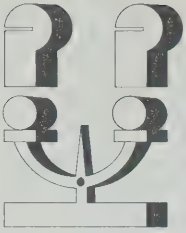
The laser's "coherence" permits the beam to be focused onto a tiny area. Temperatures far higher than that of the sun's surface can be reached.

Lasers in use

The laser is already saving money for a variety of industries. Until the laser was developed, for instance, there was no effective way to weld tiny electronic wires as thin as only thousandths of a centimeter. There was also no quick way to bore the tiny hole in a diamond used as a mold to form such fine wire. It used to take two days of painstaking work to drill a single diamond. Now, a laser beam drills the hole in two minutes.

Dentists have "flashed" human teeth with a laser beam and have found that the tooth's surface is fused in a way that reduces later decay. An experimental cane for the blind has even been developed. It sends out two laser beams. When the beams sense an obstacle, a feedback mechanism causes a slight vibration in the cane's handle to warn the user of the obstacle. In a decade or two, laser beams may even peel potatoes in the kitchen.

Lasers, in short, are no longer just a promise of the future. They've been zapping holes in razor blades for years now, but the slow transition from the laboratory to the outside world is well under way.



A thought and discussion question

Our Visual Environment: Light or Blight?

The light that comes to our eyes is free and uncontrolled. No regulations state who shall or shall not view the splendor of a sunset, or a vista of rolling hills, or inspiring architecture. But there are also few regulations governing the squalor of trash-filled vacant lots, or tattered billboards, or crumbling buildings. And where laws do exist, they are seldom enforced uniformly.

According to common law, a person's property is that person's alone to use or abuse as he or she sees fit. Yet it is common practice to uphold public nuisance laws against people who make noise after certain hours, even if they are on private property. If sound waves can cause nuisance, can't light waves also present a public nuisance? The appearance of a property is, in a sense, part of the visual environment, which is shared by all. Should it be protected for the benefit of all?

Careful experiments have long shown that the appearance of the environment affects those who live in it. Red surroundings, for example, can cause people to overestimate time and the size of objects. Green or blue surroundings can cause underestimates in these areas. Some experiments quite a few years ago showed that the colors blue and magenta had a quieting effect on mental patients, while red-yellow shades had a stimulating effect. Look down the average store-lined street and note the colors most used in signs and windows. In a way, we are all inmates in this stimulating environment. Is our own need for quieting influences being neglected?

The brightness of light can also affect people. You yourself have probably seen how a sunlit sky can cheer people the moment they step outside. The same sky, streaked and clouded with the grey smudge of smog, can put a sense of gloom into anyone. Air pollution has also taken all but the brightest stars out of many skies, depriving us of an ancient source of wonder and knowledge. Apart from the health hazards and economic waste of air pollution, might it be worth the cost of cleaning up the air to regain the sight of sunny skies and stars at night?

OUNTRY CLUB
Tucson's Only
Complete Car
Care Cervice
B.F.Goodrich
RANCHO
Precision Motors
NTIAC
Saxon
Sandwich Shoppe
NO U TURNS HERE
ANDY'S
Coca-Cola
Center
OPEN 24 HOURS
OPEN 24 HOURS
OUR FOOD IS RATED G GREAT

Billboards and other advertising also enter into any consideration of visual pollution. Some states already have laws prohibiting signs near their highways. The United States government has banned signs from some scenic stretches of interstate highways. The resulting gain in natural beauty has been appreciated by the many people who travel by car. Could the same regulations be applied in cities to prevent scenes like that in the illustration from becoming the rule in our country? Or would such control interfere with freedom of speech? Individuals or a company, for instance, might feel that putting a sign on property near a highway is a right guaranteed by the constitution. If something can be printed in a newspaper or magazine, they might say, it can be printed anywhere.

The confusion of signs in cities and towns adds to the chances for missed traffic signs, stop lights, and even people crossing streets. There are laws in some places prohibiting signs that resemble traffic signs in shape or color. But could we hope to clear up our view in the cities enough so that it is not just *possible,* but easy and safe, to drive in them? And who could or should do this huge job? Should it be handled by the federal government, state or local laws, citizens groups, or campaigns for control by businesses and individuals themselves?

Junkyards and unsightly construction are also part of our visual pollution. But can we make businessmen and landlords foot the bill for removing or covering up eyesores?

And what about the need for beauty in the homes and buildings that surround us—not just neatness and cleanliness, but a step above these. Our public buildings were often, in the past, designed and ornamented by the best architects and artisans available. The tradition of devoting resources and wealth to achieve an example of fine public architecture dates even farther back than the building of the great cathedrals in Europe.

In the Middle Ages, in cities such as Paris, Reims, and Nuremberg, the whole town would contribute money, materials, and labor, often for a period of centuries, to erect a monumental place of worship that would be more than just the necessary roof and walls. It gave the people a priceless feeling to see their work rise above the everyday structures around them.

Even today, public libraries, museums, and other buildings in some of the larger cities stand as examples of this same goal. But the cost of fine architecture is going up. Smaller towns and communities often settle for less costly buildings, which, when built, are adequate but definitely not inspiring. Because they are built quickly and cheaply, they hardly last a few generations. And in the cities, buildings turn dingy due to the air pollution, and cannot be kept looking as good as new. Granted, citizens have varying tastes in architecture, but could—or should—measures be taken to improve the general level of this important part of our environment? Should private, as well as public, buildings be included?

If architectural codes, now being discussed in many circles, are enacted, should they include visual standards, as well as structural ones? Can the ideas of space and light and a feeling of "elbow room" be legislated, when laws must deal in the concrete terms of length, width, and weight?

Is there any hope for correcting these many forms of visual pollution? Is the problem important enough to merit local and national attention? Can the resources be mustered to make a start? And, perhaps most important, will people see any need for the effort?

What do you think?

If you would like to read more about this subject, look up the following topics in *The Readers' Guide to Periodical Literature,* in your library card catalog, or in an encyclopedia:

Advertising

Architecture

Color, psychology of

Environment

Law—civil, common, and roads and traffic

Lighting

Pollution

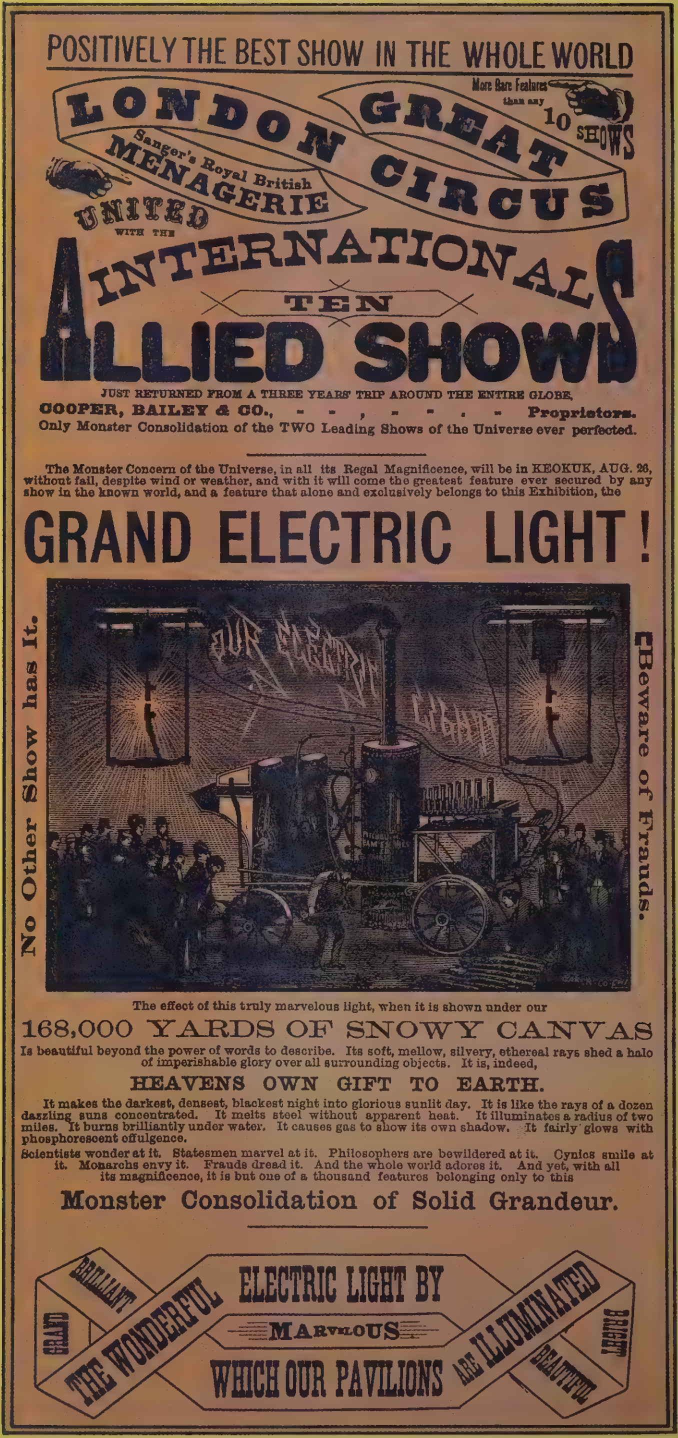
Smog

Unit 2: Electricity

Ten . . . Nine . . . Eight . . . Seven . . . Six . . . Five . . . Four . . . Three . . . Two . . . One . . . Ignition . . . Blast off!

As the giant rocket with its manned spaceship roars off, turn for a moment to the scene inside the control room. Panel lights are blinking. Computers are whirring. TV monitors are glowing. All are keeping tabs on the rocket and its crew. Life is held in the balance as each control, every monitor, does its job accurately, dependably, and . . . *electrically.* Without electricity, the rocket would never leave the pad! And without electricity, the spaceship and its crew would never return safely to earth.

You are just as dependent upon electricity as the spaceship launch. Imagine what your life would be like if suddenly you had to do without electricity. In your home or school there would be no lights, no heat, no hot water. Outside there would be no street lights, no traffic signals. Elevators would come to an instant halt no matter where they were. And electric railway trains would stop no matter where they were. Life would be different and rather difficult without electricity.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Is beautiful beyond the power of words to describe. Its soft, mellow, silvery, ethereal rays shed a halo of imperishable glory over all surrounding objects. It is, indeed,

HEAVENS OWN GIFT TO EARTH.

It makes the darkest, densest, blackest night into glorious sunlit day. It is like the rays of a dozen dazzling suns concentrated. It melts steel without apparent heat. It illuminates a radius of two miles. It burns brilliantly under water. It causes gas to show its own shadow. It fairly glows with phosphorescent effulgence.

Scientists wonder at it. Statesmen marvel at it. Philosophers are bewildered at it. Cynics smile at it. Monarchs envy it. Frauds dread it. And the whole world adores it. And yet, with all its magnificence, it is but one of a thousand features belonging only to this

Monster Consolidation of Solid Grandeur.

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Chapter 6: Measuring Electricity

When you turn on a TV set, you probably never think about the "amount of electricity" you are using. Only muffled complaints of "You got that thing on again?" and "Costs money to run that set night and day!" take you away from your viewing. Your lack of concern is understandable. How in the world is the electric company going to know if you've got the TV turned on or not?

The fact is, the electric company *does* know how much electricity your family uses each month. And they do bill their customers for the total amount used during the billing period. How do they do this?

In this section you will begin your study of electricity by finding some basic ways to measure quantities of electricity. In addition, you will learn what it takes to make electricity flow.

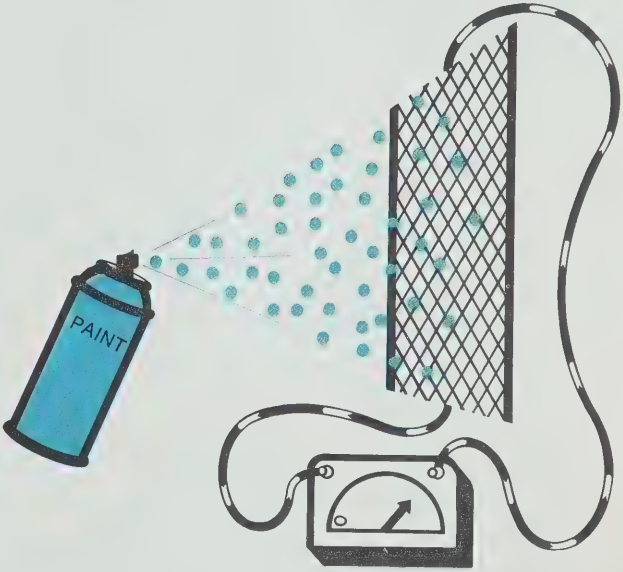
A mental model

Often, when dealing with strange and unknown events, we can go a long way toward understanding what's going on if we make a mental model. We used one such model in the light unit. There, we spoke of light intensity as being similar to the intensity of spray mist from a paint sprayer. Perhaps that same model can help explain how electricity is measured.

First, we must assume that every droplet of the mist is the same size as every other droplet. Now, suppose we wanted to measure the intensity of the mist at various distances from the sprayer.

We might be able to conjure up a sort of "mist-detector," consisting of a wire screen, some connecting wires, and an electric pulse-counter. Let's say that every time a droplet of mist hits one of the fine wires in the screen, a tiny pulse of electricity is sent along a wire to the counter. A second wire, from the pulse-counter back to the other side of the screen, completes the path for the pulses.

We are now able to measure the spray. All we have to do is count the number of electric pulses per second.

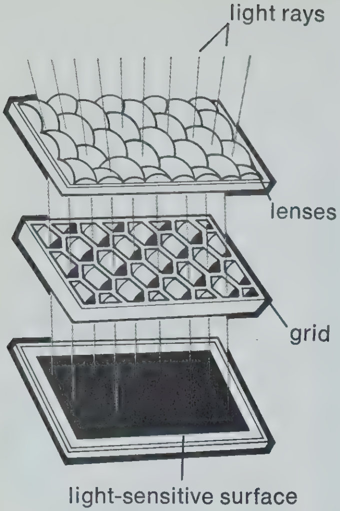


6·2

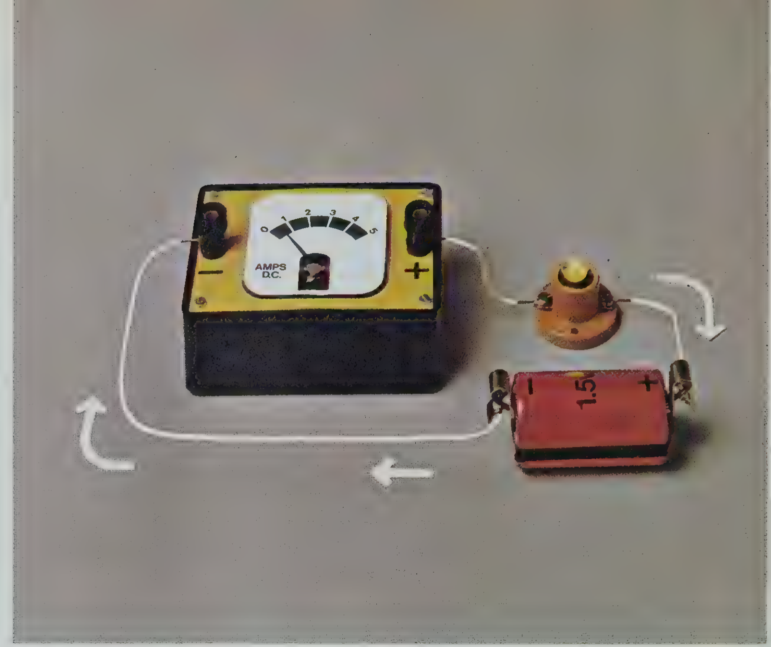
However, the paint mist is so fine that the number of pulses is extremely large—much too large to count. So, instead, we count groups or units of pulses per second. Then we will know how many units of mist are hitting our screen per second.

Although our paint "mist-detector" is strictly imaginary, there is a similar device in the real world. It is the light meter. In it, there is a light-sensitive surface which acts just like the screen in our model. As "droplets" of light strike this surface, pulses of electricity are sent along a short wire to a counter.

In this case, the counter is connected to a dial on the face of the light meter. As more light per second reaches the



6·3 Light-collecting parts of a light meter



6·4 Electric pulse-counter in a simple circuit. Notice that the needle is not exactly on a number. Meter readings throughout this unit are not exact. Light bulbs and batteries do not always work at their ideal levels.

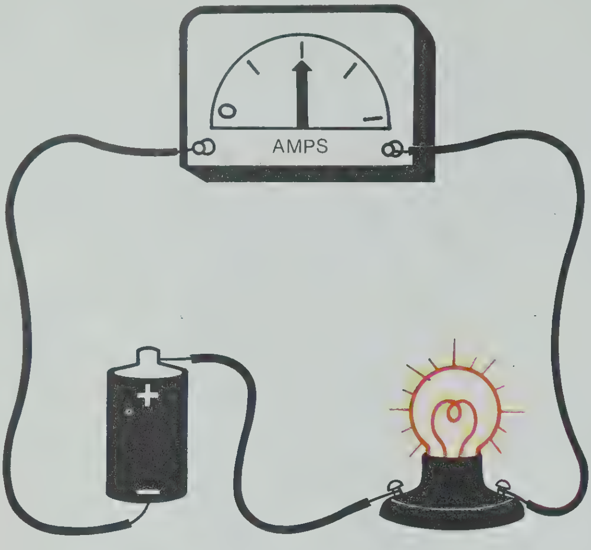
sensitive surface, more pulses per second pass through the counter. And more units of pulse per second are recorded by the counter. As a result, the reading on the dial becomes higher.

Fascinating as these light-sensitive surfaces can be, let us turn our attention to the pulse-counter. It turns out that a light meter isn't the only place you will find this device. In fact, the electric pulse-counter is a very common measuring instrument with many, many uses (figures 6·4, 6·5, and 6·6). But, first, a word about those "pulses."

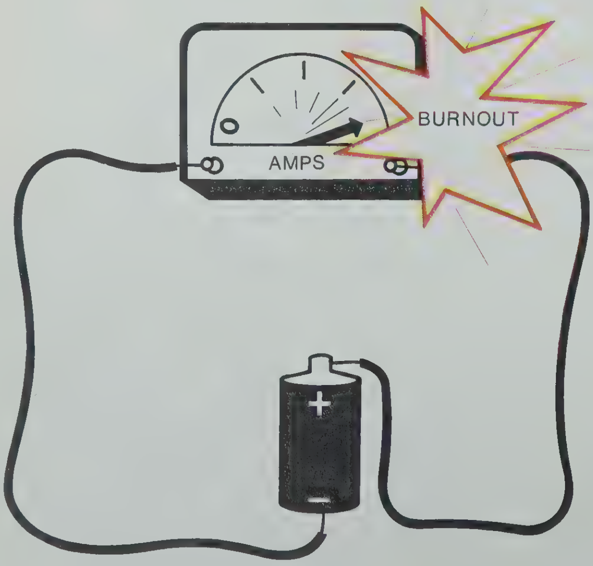
The pulses are not easily separated, one from the next. But in our model they are of equal size. And even if the pulses are all run together into a continuous stream, we can still imagine the stream to be made up of a definite number of these "pulses." The scientific name for each unit of pulses of electricity is a *coulomb*. And the name for the

6·5 Some cars have an electric pulse-counter on the dashboard. In this car, it is next to the speedometer.

6·6 Electric pulse-counters in an airplane control panel



6·7a



6·7b

6·7 Ammeters are very delicate instruments which can burn out very easily if too many coulombs per second (amps) pass through them. Therefore, whenever an ammeter is used in a circuit, the circuit must also contain a user of electricity other than the ammeter.

stream of moving pulses is *electric current*, or simply *current*. We will use these terms from now on.

Thus, we can now speak of a "coulomb-counter," and we find that such a device can be used to count coulombs of electricity going through a wire no matter how or where the electricity originates. But because "coulomb-counter" is rather a mouthful to say each time, we will call it by its more formal name, an *ammeter* (figure 6·7).

Most often we are interested in the rate of flow of electricity, or the number of coulombs streaming through a wire each second. The scientific term for coulombs per second is *amperes*, or *amps*, for short. One amp is the same as one coulomb per second. If you look at any of the meters used to measure the rate of flow of electricity, you will see the word *amps* written right on the dial. This tells you that it is an ammeter.

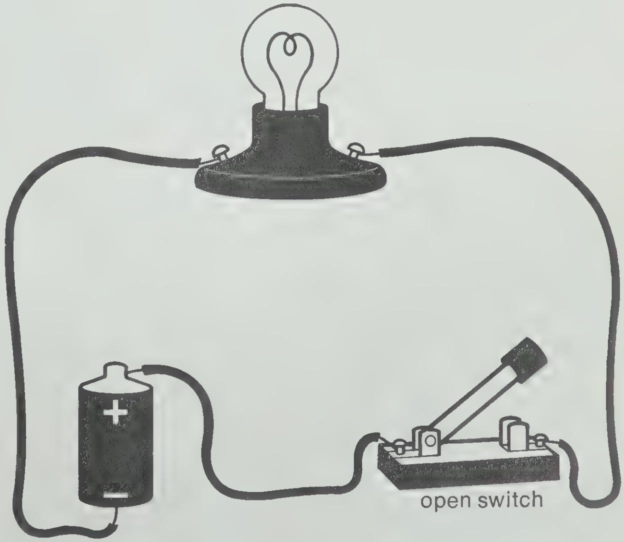
Before we begin measuring electric currents, one important idea must be made clear. In order for electricity to flow in the first place, there must be a complete path or *circuit* from one side of a source of electricity to the other side of the source. For example, if an ordinary flashlight battery is to be used to provide an electric current, then a wire must lead from the small knob at the top of the battery, around to the bare metal at the bottom. If this path is broken or disconnected at any point, electricity will no longer move around the circuit.

In most cases, there will be one or more devices that use electrical energy connected in the circuit. They will be connected so that they become part of the pathway. In other words, the electric current, which is a source of electrical energy, must flow through them in order to get back to the source. The same is true of an ammeter. It must be made part of the circuit so that it can count the coulombs per second passing through. If the circuit is broken, the ammeter will show no reading.

Since light bulbs are devices that use electrical energy, they also will not work without a complete circuit. For a bulb to light, electricity must go through the tiny wire inside the bulb. Electricity causes this wire, called the *filament,* to get so hot that it glows. If the filament should break or burn through, the circuit will be broken and no more electricity can flow through the bulb.

In all practical uses, to turn off an electrical device, you want to break a circuit on purpose, without burning through a filament or cutting a wire. This is done with a device called a *switch.* Opening a switch breaks a circuit and stops the flow of current. Closing a switch completes a circuit and the current flows once more.

In order to have a complete circuit, not only must all the parts be connected, but they must also be made of materials which readily carry electricity.



6·8

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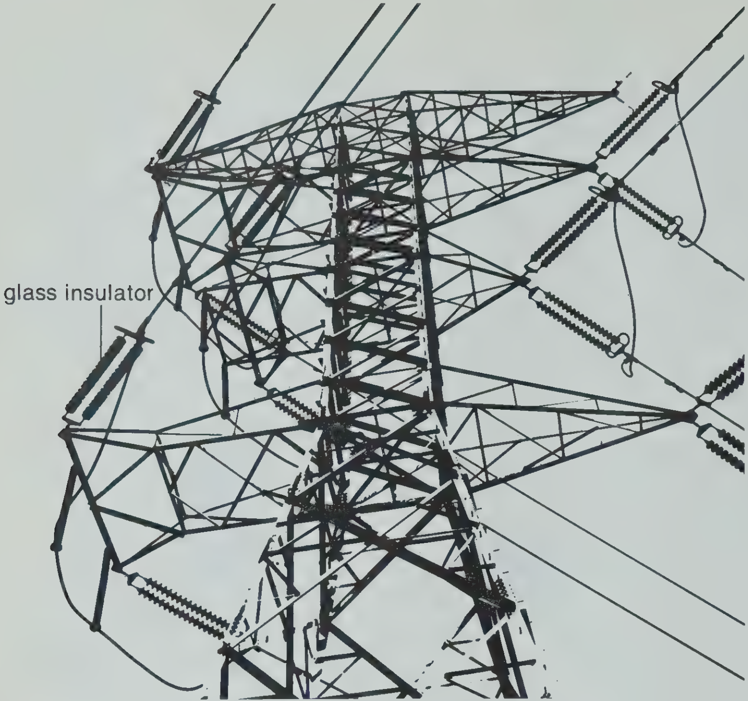


6·9

That is, all the parts of a circuit must be *conductors.* They must be made of copper, aluminum, or other metals that conduct electricity.

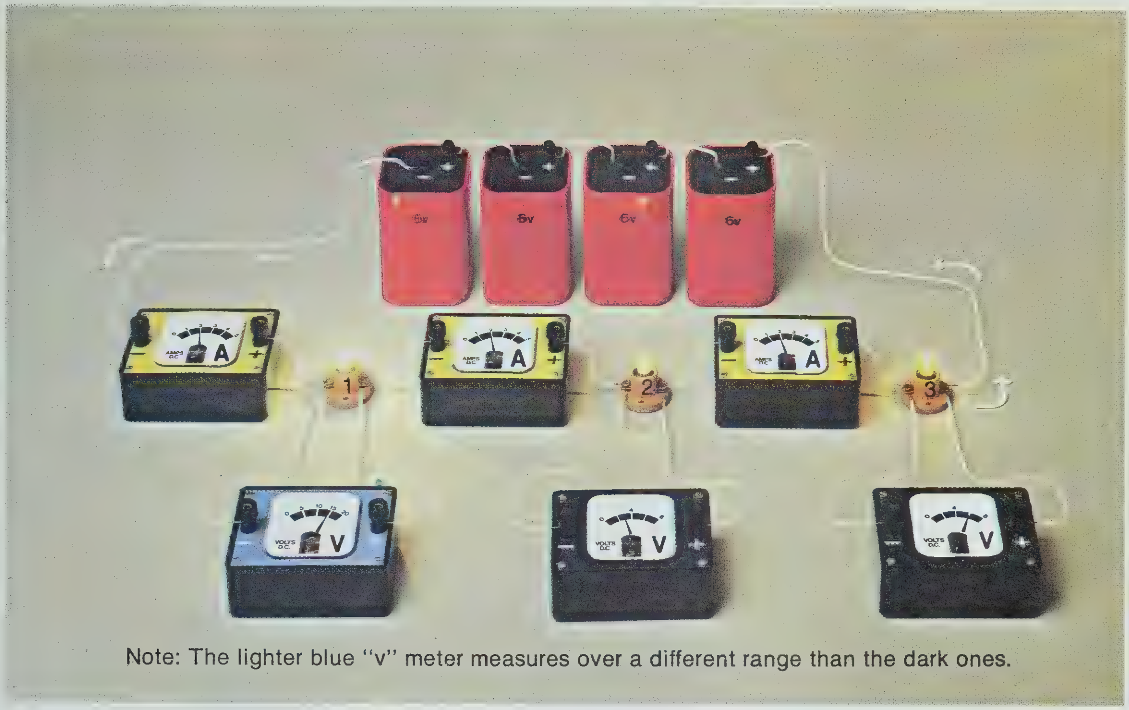
All materials will conduct *some* electricity. But one group of materials, called *insulators,* conducts so little electricity that they are, for all practical purposes, nonconductors. Insulators are used to keep a current within its desired path by forming barriers. Insulators are like walls that keep electricity in the right places. For example, wires are covered by insulators to keep the electric current where it is supposed to be instead of jumping to other wires or nearby conductors. (Air, too, is a conductor.) You have probably seen the long glass insulators which keep electric transmission lines from touching the tall steel towers supporting them (figure 6·9). If the glass insulators were not there, nothing would keep the electric current in the lines from going through the steel tower, right into the ground.

Bright lights and dim

In figures 6·10 and 6·11 there are three lamps of varying size and brightness with ammeters attached between them. The ammeters (labeled "A" meters) serve as links from one bulb to the next. Each coulomb of electricity must move through an ammeter before it gets to the next bulb. However, other meters (labeled "V" meters) are attached so that the current splits into two parts. "V" meters are designed so only a tiny part of the current goes through them. Almost all of the current goes through the bulb.

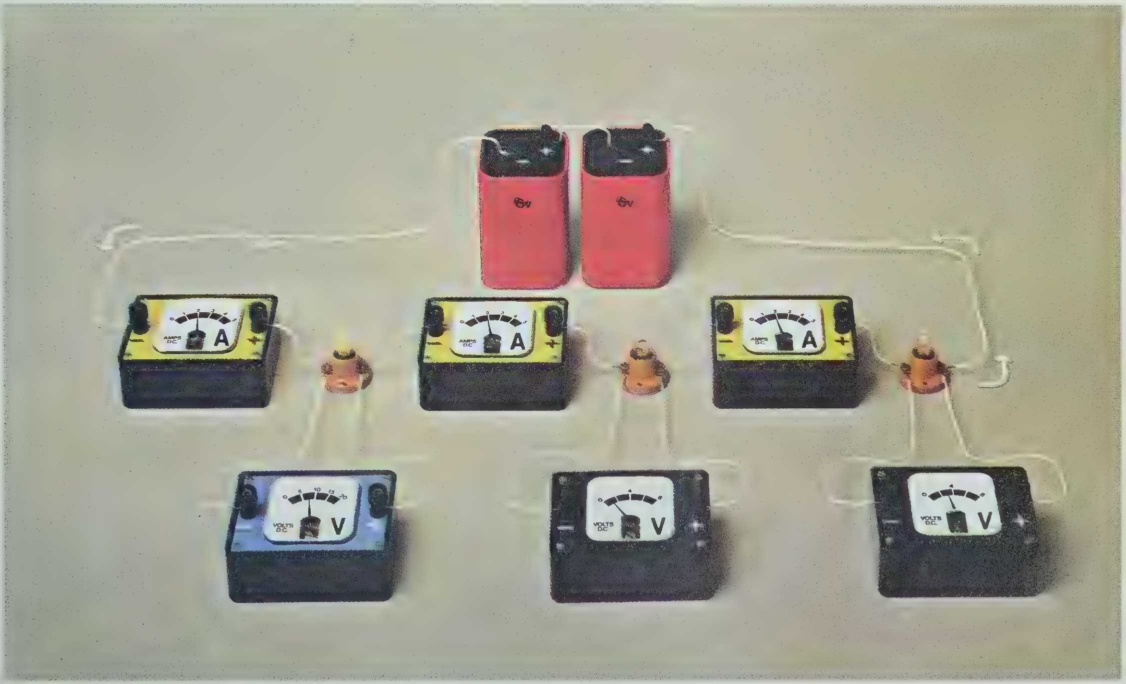
The "A" meters all read the same in each figure. But notice the readings on the "V" meters. How do the readings on the "V" meters relate to the brightness of the lamps? Notice that the readings on the "V" meters are all different, yet all bulbs get their coulombs of electricity from the same source. How is this explained?

Again, we have the problem of picking a suitable model. In this case, we want to choose some "thing" to stand for a coulomb of electricity and find out what happens as the coulomb passes through the light bulb.

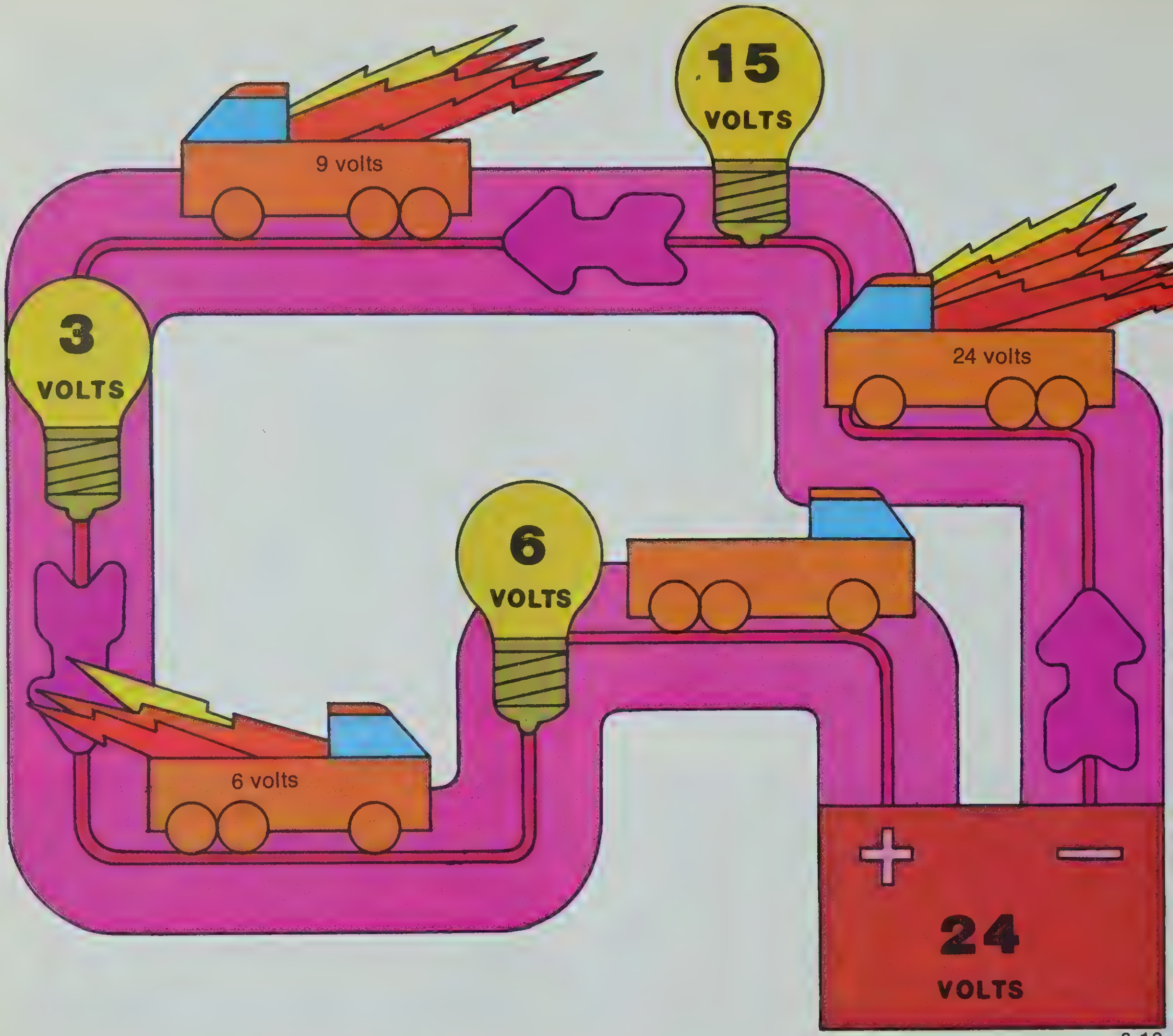


Note: The lighter blue "v" meter measures over a different range than the dark ones.

6·10



6·11



6·12

Nothing we can think of exactly fits because a coulomb of electricity is like no physical thing we can see, touch, or taste. So, realizing our model is not exact, let us think of a coulomb of electricity as a tiny, invisible dump truck traveling down the wires at great speed. Furthermore, there is an endless stream of dump trucks, bumper-to-bumper, all moving down the wire at the same speed.

Now comes the hard part. Besides trying to think of dump trucks that aren't there, we must also imagine an invisible cargo, called *energy*.

Energy is not a thing, not a fluid, not a substance of any kind. You cannot find some energy and pick it up by the scruff of the neck. Rather, energy is just a sort of "ability" to get things done. It is this "ability" which is picked up by our dump trucks as they leave a source of electric current (such as a battery). This "ability," or energy, is carried by each truck to the first electrically operated device, in this case a lamp. There, some of it is "dumped." The delivered energy makes the lamp glow and the truck continues to the next user.

In figure 6·12, you can see that each dump truck is being supplied with 24 units of energy as it leaves the source. The first device gets 15 units of energy, leaving nine still in the truck as it drives on to the next device. There, three units are deposited, and the remaining six units are delivered to the last device on the "route."

What we are saying, then, is that each coulomb of electricity has a certain amount of energy as it travels along a wire. This energy is furnished by the electrical source and some of it is taken away by each device in the circuit. One by one, the devices take energy from every coulomb of electricity passing through them, until finally, the coulombs return to the source to pick up a new supply of energy.

Now you are ready to understand the readings on the meters. The three ammeters ("A" meters) in figure 6·10 tell the number of coulombs per second passing through each part of the route (dump trucks per second). Of course, if there is one coulomb per second passing a point near the first lamp, there will be one per second everywhere else on the route, too. This is because in the dump-truck model trucks are moving bumper to bumper at equal speeds.

Now, what about the "V" meters?

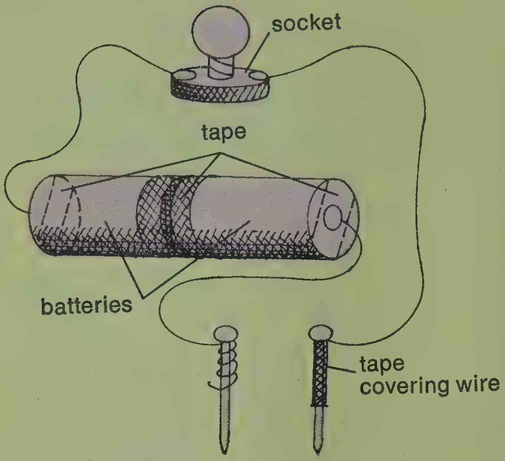
The "V" meters show the amount of electrical energy per coulomb being received by each lamp. Fifteen units per coulomb are being used by the first lamp in figure 6·10 so the first "V" meter reads "15." The "V" meters are called *voltmeters.* And as you might have guessed, electrical energy per coulomb is measured in units named *volts.* Thus, the first bulb uses 15 volts per coulomb, the second uses 3 volts per coulomb, and the last one uses 6 volts per coulomb. Altogether, the source supplies 24 energy units for each coulomb, so we say it is a 24-volt source.

Figure 6·11 shows a 12-volt source replacing the 24-volt source in the original circuit. What differences can you see in the readings of the ammeters and the voltmeters? Note that a voltmeter is always attached with one wire at each side of a user of electrical energy.

TEST YOURSELF

1. *a. What is an amp? b. What is a volt?*
2. *Tell how the terms conductor, insulator, and circuit are related.*
3. *In a circuit, how is a voltmeter attached differently from an ammeter?*
4. *Suppose there were three electrically operated devices connected in a row to a battery of unknown voltage. Each device has a voltmeter attached to it in the proper fashion. How could you use the readings on the three voltmeters to find the voltage of the battery?*
5. *In figure 6·10, suppose we reversed the positions of bulb #1 and bulb #2. How many units of energy would the little dump truck in figure 6·12 now be carrying as it travels from the new bulb #1 to the new bulb #2?*

ON YOUR OWN



Test conductors of electricity

Have you ever wondered whether something is a conductor of electricity? You can make a conductivity tester out of the following materials:

2 1 1/2-volt batteries size D
1 3-volt flashlight bulb in a socket
3 25-cm (10-in) lengths of #20 insulated copper bell wire
2 iron nails, 5 cm (2 in) long
Friction or adhesive tape

PROCEDURE: Connect the batteries, wire, and socket as shown in the drawing. (CAUTION: It can be very dangerous to do this experiment with any other source of electricity.) Remember that you must strip the insulation from the ends of the wire where it will be in contact with another part of the circuit. Remove 8 cm (3 in) of insulation from the free end of each wire, and wind one free wire end around each nail. Cover the part of the nail attached to the bare wire with tape.

Test the circuit by touching the nails to each other. The bulb should light. Now you can test substances to find whether they conduct electricity.

Touch the nails to each end of a key. Does the bulb light? Touch the nails to each end of a penny, nickel, dime, quarter, and half dollar. Try a silver dollar if you have one. In which cases does the bulb light? Test a paper clip, an eraser, a pencil lead (break the pencil and sharpen both ends), a comb, a hairpin, a piece of aluminum foil, and other familiar objects.

Immerse the nails in water, salt water, and sugar water. In which cases does the bulb light? Dry the nails. Put a small amount of salt on a napkin and test it. Try a small amount of sugar. Does the bulb light for either substance?

Those Were the Days

Early experimenters with electricity

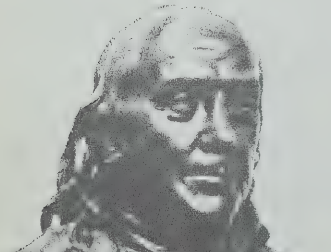
Everybody knows the famous Ben Franklin kite-flying story. The man recognized as America's leading scientist of his time really risked his life on that experiment. And for what? To prove his point that lightning was nothing more than the release of an electrical charge (group of pulses) built up in a storm cloud. He claimed that when the charge reached a point where it no longer could be contained, it jumped to neighboring clouds or to tall objects on or near the ground.

To test his hypothesis, Franklin attached a pointed metal rod to the top of his kite. He also attached a key to the lower end of the kite string. He expected the rod on the kite to pick up the jumping electric charge. He thought the charge would then travel down the string to the key. Sparks appeared around the key when lightning hit the kite. Franklin felt he had proved his hypothesis.

Fortunately Franklin was not killed by this dangerous experiment. Some other scientists were. To protect himself, Franklin used an insulating dry silk ribbon between the kite string and his hand. And, luckily, the bolt of lightning that hit his kite was not strong enough to jump across the insulation.

Franklin put the results of his experiment to good use by inventing the lightning rod. This device is a metal pointer mounted on top of a building and connected by a wire to the ground. It provides a safe path to the ground for jumping charges in an electrical storm. It keeps the charge from moving through a building where it could start a fire.

Few people know the more whimsical side of Franklin, however. Just for fun, he invented a lightning rod that rang chimes when the air was charged. He also made a portrait of the King of England. To the delight of practical jokers everywhere, he electrified the king's crown so that anyone who touched it got the shock of his life! Another time Franklin staged a grand "electrical picnic" for his friends. He told them that "spirits are to be fired by a spark sent from side to side through the river without any other conductor than the water. . . . A turkey is to be killed for our dinner by an electric shock and roasted . . . before a fire kindled by the electrified bottle."



6·15 Benjamin Franklin

Two kinds of electricity

Charles François DuFay (dü fā′), a scientist who lived just before Franklin, also used electricity to entertain. DuFay was a member of the court of Louis XV, and performed before gatherings of French nobility.

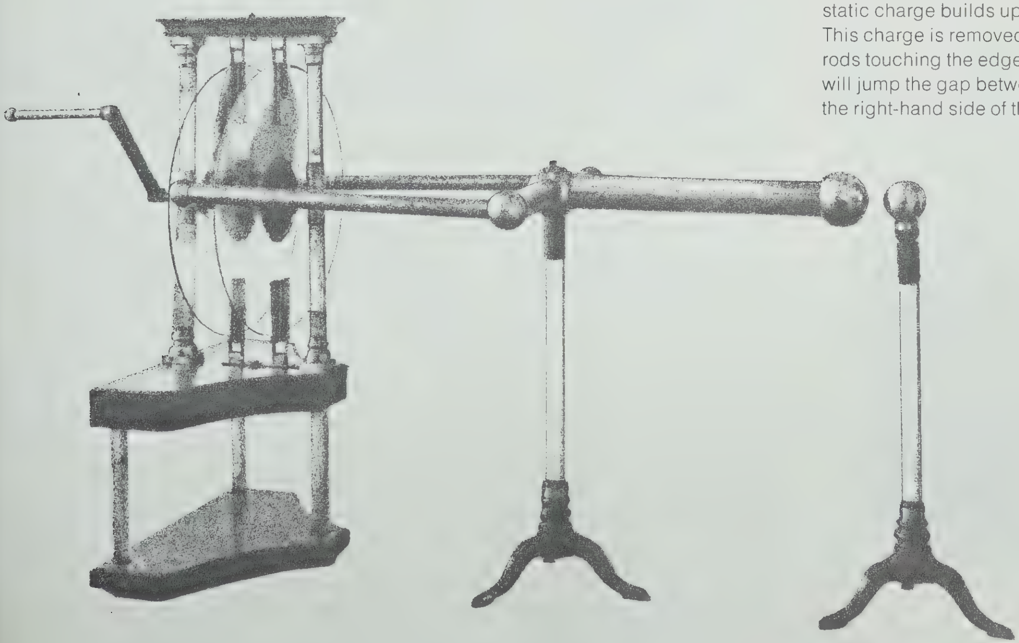
In his more serious work, DuFay identified what he thought were two kinds of electricity. He called the kind of electricity that builds up on glass when it is rubbed with fur "vitreous electricity." And he referred to the electricity that collects on amber when it is rubbed with fur as "resinous." He found that all objects with "vitreous" electricity repel each other as do all objects with "resinous" electricity. But objects with "vitreous" electricity attract objects with "resinous" electricity. Franklin later called these two different forms of electricity "positive" and "negative." And today we refer to the electricity that collects when one material rubs against another as *static electricity.*

Static electricity, like current electricity, consists of charges. If the substance being charged is part of a complete circuit, these charges move around the circuit and do not accumulate in any one spot. And if the substance is not part of a complete circuit, the charges collect on that substance. But most substances are not

6·16 Sketch of Duc du Chaulnes' improvement of Dr. Franklin's kite experiment. Du Chaulnes sits suspended above the ground and insulated from the ground. There is a lightning rod above his head and he is flying his kite by remote-control.

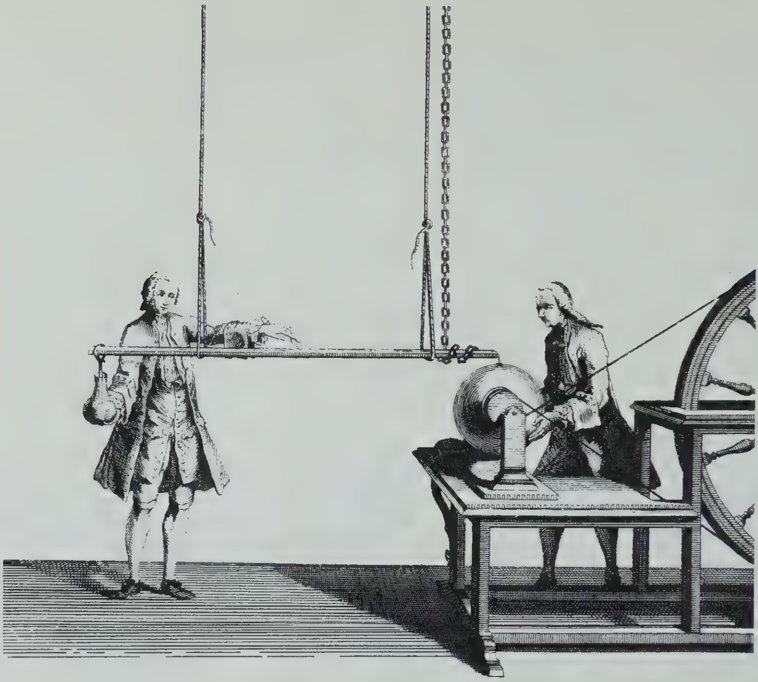
normally charged. So it is quite natural for sparks to jump away from a charged substance just as lightning jumps out of the clouds. Such a discharge occurs when you walk on a wool rug on a dry day. Charges of static electricity build up on your body and are discharged as a spark, giving you a shock when you touch an object that carries the charge away.

DuFay used static electricity for one of his favorite exhibits. He had an assistant suspend him from the ceiling with insulating silk cords. The assistant would then build an excess of harmless static electricity on DuFay with a static electricity machine (figure 6·17). When someone touched DuFay in the darkened room, large sparks jumped. The spectators were delighted.



6·17 Electrostatic machine. When the crank is turned, the glass wheels turn rapidly. As they turn, they rub against pieces of fur in the top holders. A static charge builds up on the glass. This charge is removed by the brass rods touching the edge of the glass. It will jump the gap between the knobs on the right-hand side of the picture.

6·18 Sketch of van Musschenbroek's experiment. Van Musschenbroek is operating the electrical machine while his assistant is holding the Leyden jar. The assistant is moving his other hand toward the conducting rod where he will be shocked by the large discharge of electricity from the jar.



Collecting electricity

At first, both Franklin and DuFay thought that electricity was some kind of invisible fluid. They said it flowed through wires in much the same way as water flows through pipes. This fluid model gave rise to many terms, such as "current," which are still in use today.

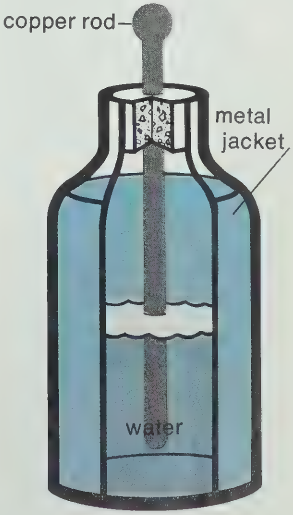
Experimenters before Franklin and DuFay thought that if electricity is a fluid, one should be able to collect and store it. But what kind of container might be suitable for collecting the magical electric fluid? Could it be contained in a bottle? Would a bottle filled with a conducting substance, such as water, hold a highly concentrated amount of electricity?

In 1745, Peter van Musschenbroek (vän mŭs′en brük), a professor at the university in Leyden (līd′n), Holland, tried to answer these questions. He decided to electrify some water in a glass jar. He put a wire from an electrical machine into the water in the jar (figure 6·18). An assistant held the jar in his hand. He had no ill effects and expected none. After the water inside the jar had been charged for a while, the machine was disconnected and the assistant reached up to remove the loose wire in the jar with his other hand. He was quite surprised when he received a severe jolt!

Van Musschenbroek supposed that a large amount of electricity must have been suddenly discharged when the water inside the jar was connected to the moist hand outside the jar. This large discharge could only result from a pair of opposite charges being joined. At the same time a charge was building up inside the jar, an *opposite* charge was apparently building up in the assistant's wet hand outside the jar. This is where the *ZAP* came from. The assistant was shocked because his body was part of the path for the electricity.

Van Musschenbroek tried to redo the experiment without giving his assistant another electric shock. He again ran a wire from a static electricity machine to the water inside the jar. But, this time he replaced the assistant's hand with a metal jacket covering the outside of the jar. He had two electrical conductors (water inside and the metal jacket outside) separated by a nonconducting insulator (the glass jar). He again charged the water. Then he brought the free end of the wire in the water close to the outer metal jacket. Just as he expected, a large spark jumped between the end of the wire and the metal jacket. His collecting jar became known as the Leyden jar (figure 6•19).

6•19 Leyden jar



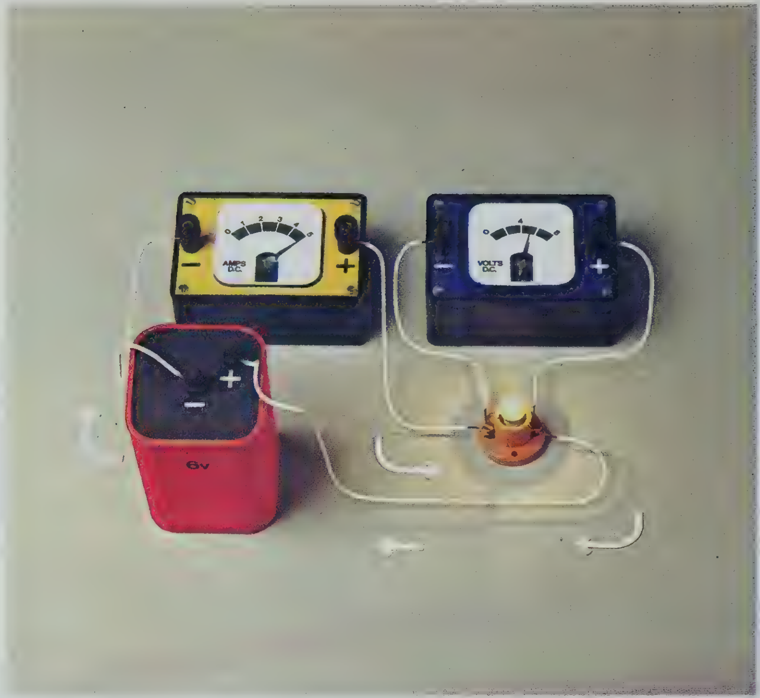
The Leyden jar quickly became popular with the experimenters of Van Musschenbroek's time. For example, Franklin's experiments with a Leyden jar led to his hypothesis about electrical charges in the clouds. Today experimenters still use variations on Van Musschenbroek's Leyden jar for storing electrical charges. Modern Leyden jars have metal conductors rather than water on the inside. We now know that the metal conductor on the inside of the jar stores one kind of charge, while the one on the outside stores the opposite charge.

Some of the ideas and activities of these early scientists seem strange. However, we still use some of these same mental models today. We say that electricity flows through a wire and that things can have a positive or a negative electrical charge.

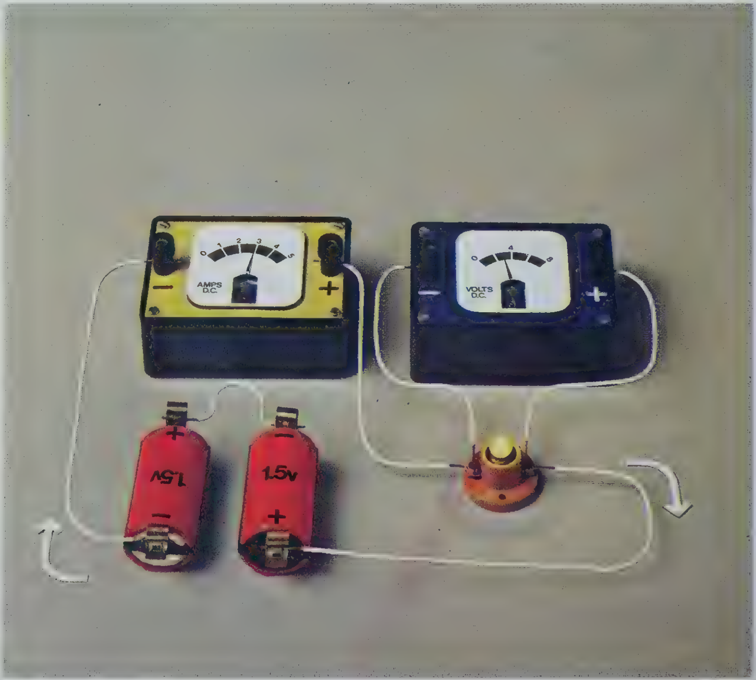
What's a watt?

If you look at the top of a light bulb, you will see a number and the word "watts." As you know, when buying light bulbs, if you want the brightest light, you should pick the bulb rated at the highest number of watts.

But what is a watt? To answer this question, compare the volts used by the bulbs in the three circuits in figure 6·20. Then compare the amps moving through the three circuits. For example, what is the voltmeter reading in the first circuit? What is the amperage through the first bulb? The bulb is rated at 25 watts. Notice how this number (25 watts) relates to the number of volts and amps. Now see if this relationship is true for the other bulbs in figure 6·20.

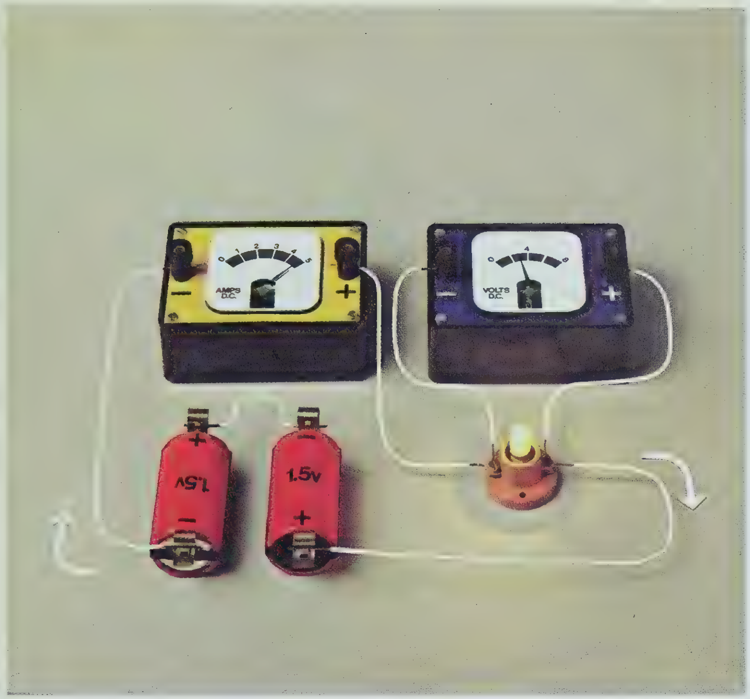


6·20a



6·20b

6·20 The bulb in section *a* is rated at 25 watts. The bulb in section *b* is rated at 9 watts, and the bulb in section *c* is rated at 15 watts.



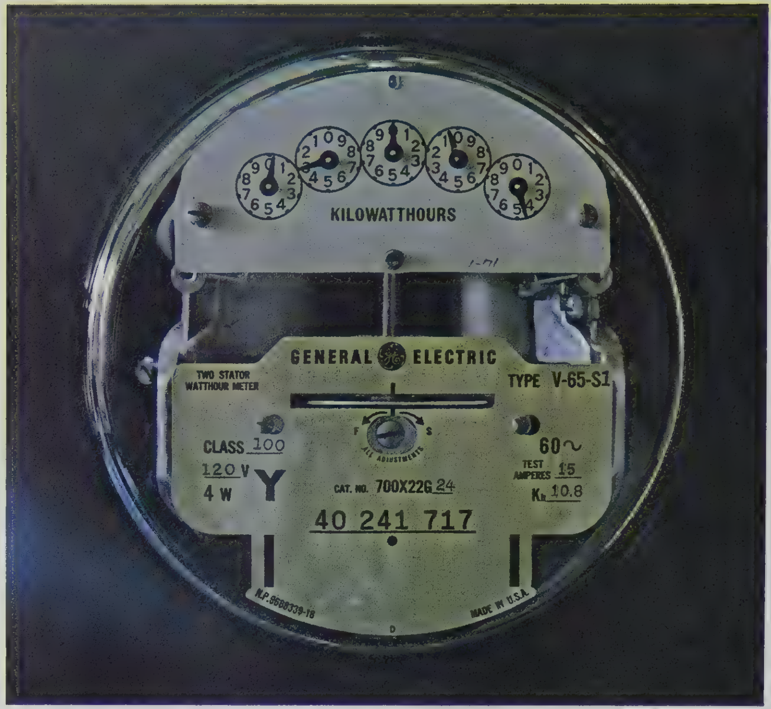
6·20c

6·21

As you might have already decided, watts are equal to the number of coulombs per second (amps) multiplied by the energy per coulomb (volts) being used by a bulb. By carrying this reasoning further, you will find that this multiplication results in energy per second. In other words, the term *watts* means "energy per second." The more energy per second a bulb uses, the brighter it burns. We might say it is a more *powerful* bulb. So "energy per second" means "power" too. In the same way, the more power a toaster or electric drill uses, the more energy per second is required from the household circuit.

There is a second rating on the top of a light bulb. This indicates the voltage at which the bulb works best. To work properly, every appliance should operate at the voltage listed on it. Then it will use power at the exact rate for which it was designed.

Watts and the electric bill



6·22 The dials on the meter register the number of kilowatt-hours being used. The dial on the right gives the number of kilowatt-hours from 1 to 10. The next dial reads from 10 to 100. The center dial reads from 100 to 1000 kilowatt-hours. The fourth dial from the right reads from 1000 to 10,000, and the dial on the left, from 10,000 to 100,000 kilowatt-hours. The reading on this meter is 3004 kilowatt-hours.

You pay for electricity according to the number of watts you use over a given time period. The electric company measures it in thousand-watt packages called *kilowatts.*

You are billed for the number of kilowatts you use multiplied by the total time you used those kilowatts. For instance, if you turn on a 100-watt light bulb for one hour, you will use 100 watts or 0.1 kilowatt of electricity for that hour. And you must pay for 0.1 *kilowatt-hour* of electricity. If you keep that light bulb on for 10 hours, you will use 10 hours times 0.1 kilowatt or 1 kilowatt-hour of electricity.

Now you can calculate what it costs to operate a refrigerator for a 30-day month. A common refrigerator uses energy at an average rate of 400 watts or 0.4 kilowatts. The motor of a refrigerator turns on when the temperature inside reaches a certain point. When the refrigerator becomes cool enough, the motor switches off again.

Suppose the total time in hours this refrigerator runs is 30 days times 12 hours per day or 360 hours. Thus the total amount of electrical energy used would be 400 watts × 360 hours = 144,000 watt-hours or 144 kilowatt-hours. What does it cost to run this refrigerator if the electric company charges three cents per kilowatt-hour?

You can also calculate the cost of playing your radio. A small table radio uses energy at a rate of about 5 watts (0.005 kilowatt). If you listen to that radio every evening, it might be on for four hours a day, or 120 hours a month. Thus you would use 5 watts × 120 hours = 600 watt-hours or 0.6 kilowatt-hours of electrical energy. At three cents per kilowatt-hour, it does not cost very much to run that radio.

TEST YOURSELF

1. *What is the unit for electrical energy per second?*
2. *How much electrical energy per second does a 120-volt coffee pot use when 5 amps are passing through it?*
3. *How many watts are in a kilowatt?*
4. *If you read by a 100-watt light bulb for three hours every night, how much electrical energy does the bulb use in 7 days?*

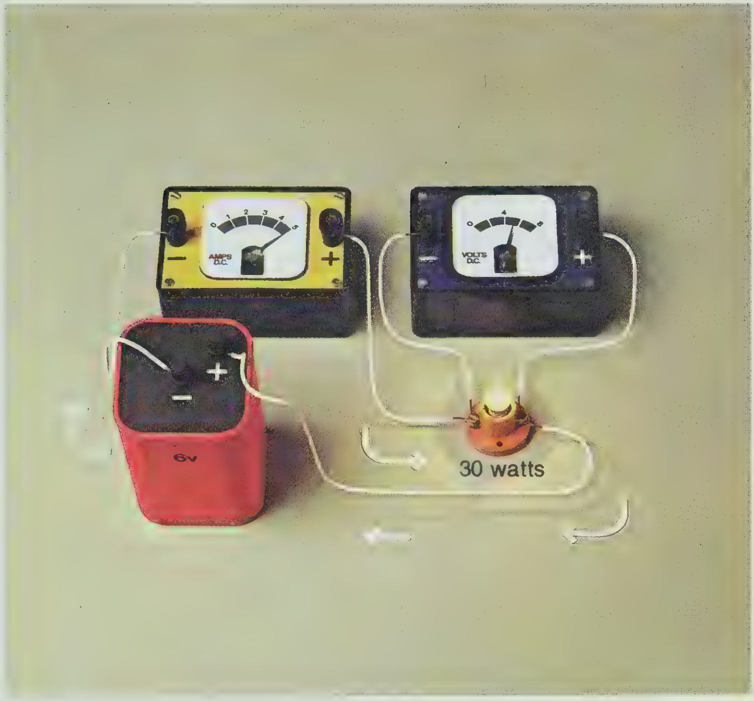
Meeting resistance

Figure 6·23 shows three different circuits. The bulb in each is using a different number of watts. But all of the bulbs are using about 6 volts. So, a different number of amps must be flowing through each bulb.

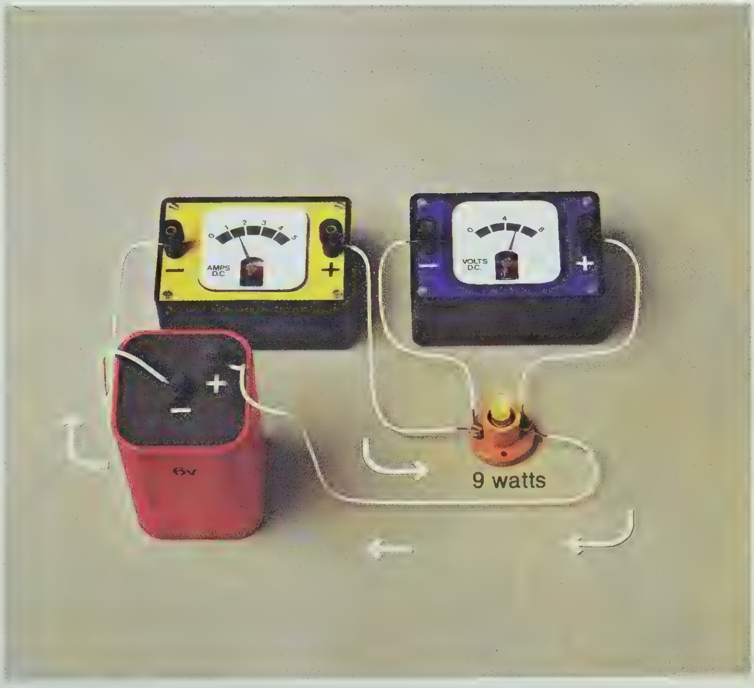
Everything else is the same in the three circuits, except the bulbs. So, logically, there must be something in the make-up of each bulb which determines the number of amps that will pass through at a given voltage. In other words, something in the bulb itself allows either a large, small, or medium number of amps to pass through it.

This characteristic which fixes the number of amps to pass through an electrical device is called the electrical *resistance* of the device. For example, a bulb through which a large number of amps pass at a certain voltage has a *low* resistance. A bulb through which fewer amps pass *at the same voltage* has a *higher* resistance.

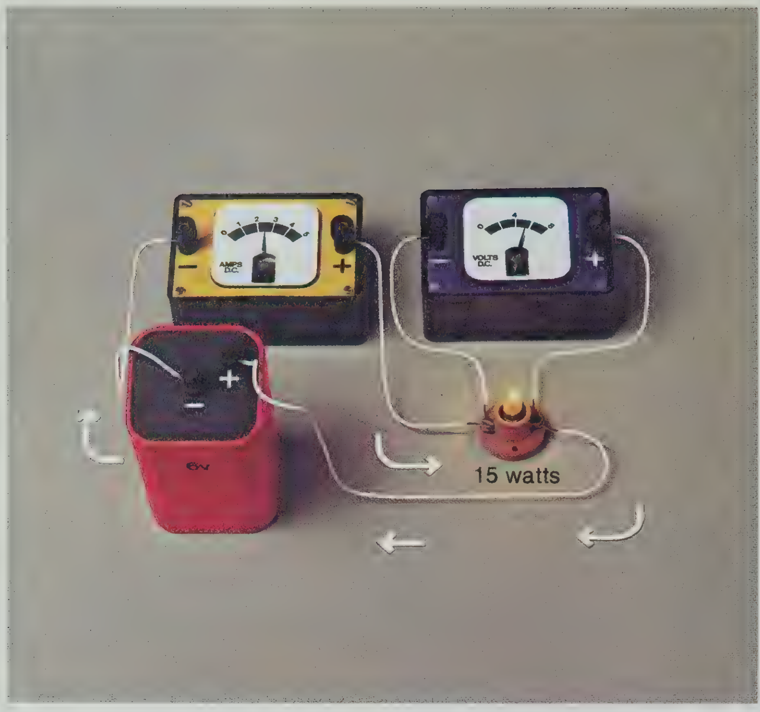
6·23 a, b, and c The batteries in these photos did not supply exactly 6 volts because they wore down slightly while being photographed.



6·23a



6·23b



6·23c

There is a simple relationship between volts, amps, and resistance in a circuit. When the resistance is measured in units called *ohms,* one ohm of resistance allows one amp of current to flow when the voltage is one volt. You can calculate the ohms of resistance of the light bulbs in figure 6·23 by using the formula: $\text{ohms} = \frac{\text{volts}}{\text{amps}}$. In other words, the resistance in a circuit is found by dividing the total amount of voltage used in the circuit by the number of amps flowing through it.

For example, look at the circuit in figure 6·23b. Six volts divided by 1.5 amps equals 4 ohms. Notice that each of the circuits in the figure has a different resistance. You get a different number of ohms for each user because each user allows a different number of amps to pass through it at the same voltage.

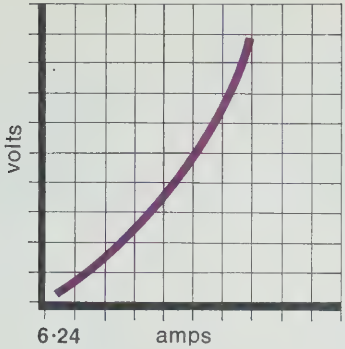
Since resistance is a characteristic of all devices run by electrical energy, such devices are often called *resistances*. For example, a refrigerator motor, a TV picture tube, and an automobile headlight are all resistances.

More resistance

There's more to electrical resistance than meets the eye. A good example may be found in an extension cord leading from an outlet to some high-powered appliance. (CAUTION: To use an extension cord in this way is an unsafe practice and may cause a fire. Normally, large appliances should be plugged directly into a wall outlet.)

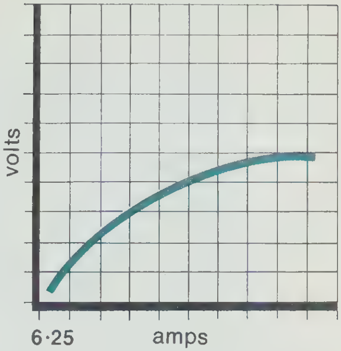
Before the appliance is turned on, the insulated extension cord is at room temperature, like everything else in the room. But after the appliance has been running for a short time, if you take the extension cord in your hand, it feels warm. This warmth results from the wire's resistance to the flow of an electric current. However, this resistance has changed somewhat during the short time since you first turned on the appliance. It has changed because temperature affects the resistance of most metals.

The resistance of copper increases as it gets warmer. When the copper wire was at room temperature it offered very little resistance and, as a result, lots of electricity surged through to the appliance. This surge of current increased the tungsten filament



6·24

carbon filament



6·25

temperature of the wire. The wire, in turn, acquired an increased resistance. As the resistance in the wire increased, the flow of current tapered off, until the wire reached some stable temperature and some stable resistance. For this reason, the extension cord remained warm instead of getting hotter and hotter in your hand.

Thus, you see that the number of ohms of resistance does not always stay the same in a given appliance or light bulb. Resistance may increase as the temperature goes up or decrease as the temperature goes down. It follows that most appliances will use electricity at a faster rate when they are first switched on than when they get warmed up to operating temperature.

You can further increase the temperature of a wire in an appliance by increasing the voltage. This has the effect of increasing the amperage, which is what heats the wire more. Figure 6·24 shows a graph of voltage versus amperage for a tungsten filament in a flashlight bulb. As you can see, the amperage through the filament increases as the voltage is increased. This additional amperage heats the filament more and more. The result is an increase in the resistance of the filament. This increase in resistance is shown by an upward curve on the graph.

On the other hand, carbon filaments, like the ones used in Edison's early light bulbs, are affected differently by increases in temperature. Figure 6·25 shows a graph of voltage versus amperage for the carbon filament of a light bulb. The resistance of a carbon filament decreases as its temperature increases. This means that carbon filaments conduct more and more electricity until they burn out.

TEST YOURSELF

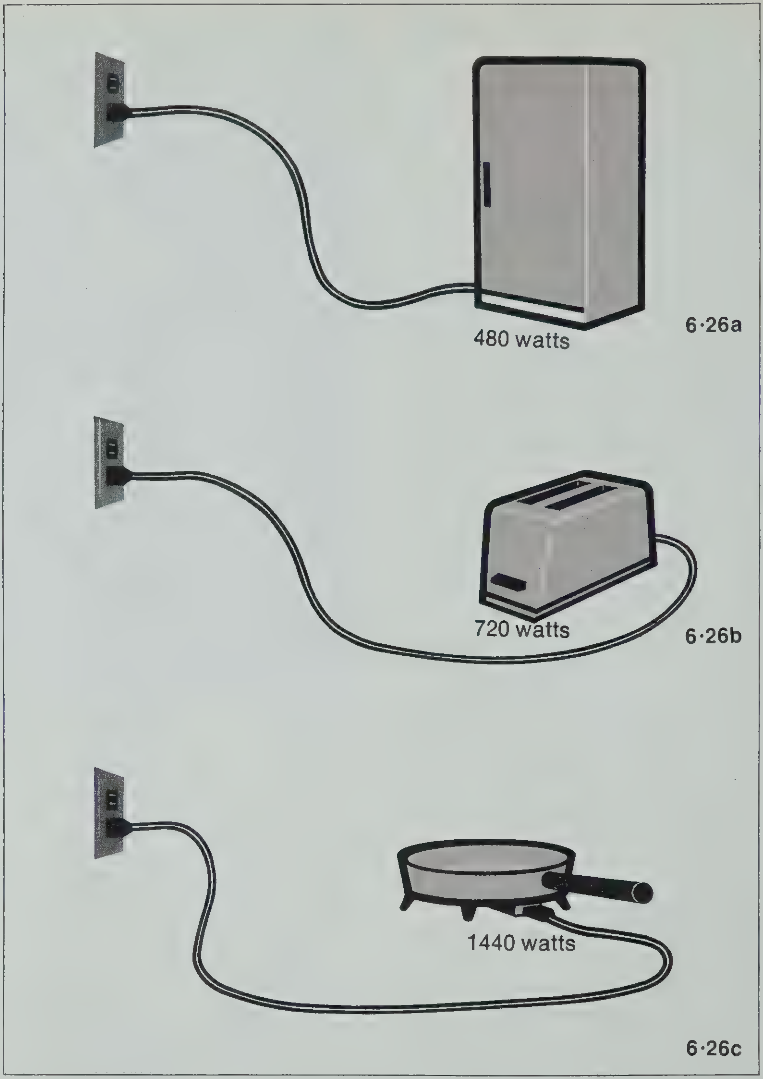
1. *How can you find the electrical resistance of a circuit if you know the amperage and voltage?*
2. *A hot plate is plugged into a 120-volt outlet. The ammeter in the circuit is reading "10 amps." What is the resistance of the hot plate in ohms?*
3. *A certain portable phonograph can run on two 9-volt batteries. If the phonograph is rated at 36 watts, what is the resistance in ohms?*
4. *Does an appliance with high resistance use more or less wattage than an appliance with low resistance if both are attached to identical power sources?*
5. *a. Back a few sections, when you were first learning about voltages, we used a "dump-truck model" to describe the volts needed by several different light bulbs. Tell how you would now expand that model to explain why one bulb always took 9 energy units from each coulomb, another took 6, and so forth (figures 6·10, 6·11, and 6·12).*

   b. Calculate the resistance in ohms of each of the bulbs in figures 6·11 and 6·12.

Most of the simple circuits you have seen so far have contained only one resistance per circuit. But, as you probably know, quite a few resistances can be added to the same circuit. Basically, there are just two ways in which electrically operated devices can be hooked together in a circuit.

Let's look at each way by going to the kitchen and borrowing a few familiar appliances. We will take these appliances, hook them up to ordinary household circuits, and measure what is happening. Assume, for easier arithmetic, that all household circuits are provided with 120 volts. In reality, the voltage does vary slightly. It depends upon location, time of day, and season of the year. People have a greater demand for electric power at different times and the power companies are not always ready to meet the demand. So the voltage sometimes varies a little.

Now, look at figure 6·26. What would be the amperage through each of the circuits shown? You remember that volts × amps = watts. So, amps can be found by dividing watts by volts.



6·26a

6·26b

6·26c

Refrigerator:

$$\frac{480 \text{ watts}}{120 \text{ volts}} = 4 \text{ amps}$$

Toaster:

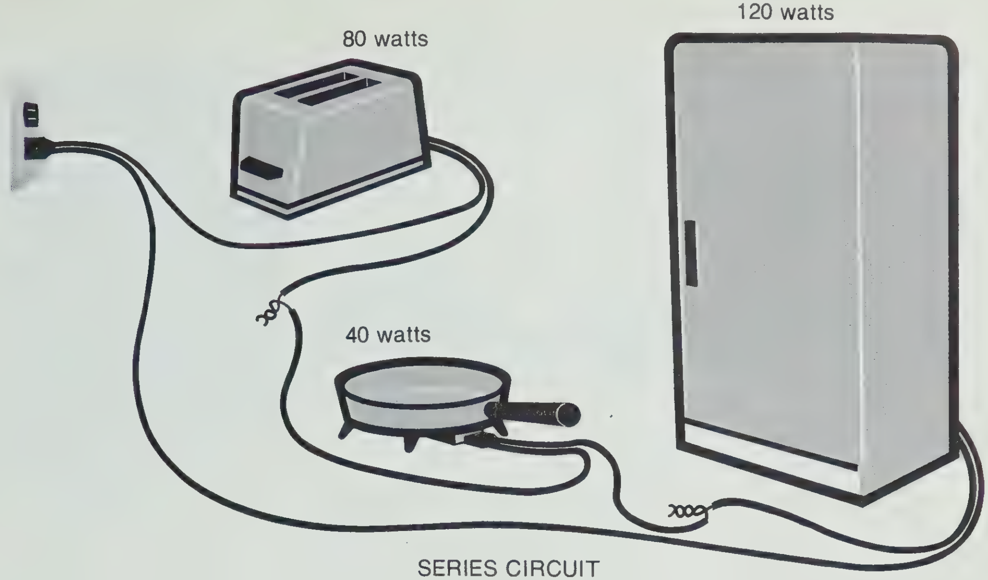
$$\frac{720 \text{ watts}}{120 \text{ volts}} = 6 \text{ amps}$$

Frying pan:

$$\frac{1440 \text{ watts}}{120 \text{ volts}} = 12 \text{ amps}$$

Next, what is the resistance of each of the three appliances?

(Remember that $\frac{\text{volts}}{\text{amps}} = \text{ohms}$.)



SERIES CIRCUIT

6·27

Refrigerator:

$$\frac{120 \text{ volts}}{4 \text{ amps}} = 30 \text{ ohms}$$

Toaster:

$$\frac{120 \text{ volts}}{6 \text{ amps}} = 20 \text{ ohms}$$

Frying pan:

$$\frac{120 \text{ volts}}{12 \text{ amps}} = 10 \text{ ohms}$$

We now know the electrical resistance of each appliance and how many amps each will take when hooked up all alone to a wall outlet supplying 120 volts. Next, let's find out what happens when we hook the appliances together.

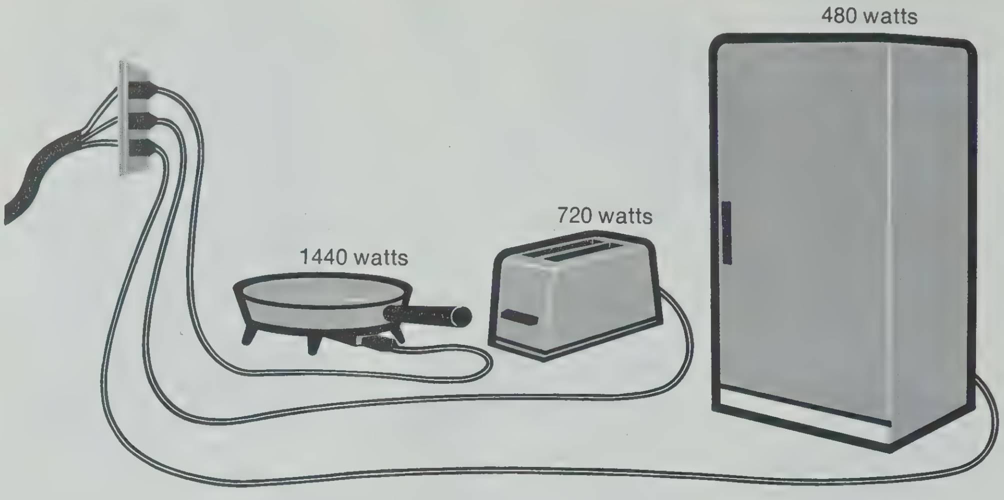
What would happen if we connected all the appliances in a straight line so that the current would have to go first through one, then another, and so on? We can find out by doing an imaginary experiment. Every appliance has a double-wire cord. Each appliance cord would have to be split down the middle and wired as in figure 6·27.

CAUTION: Such a procedure will ruin the appliances. There are also other factors involved that would interfere with an actual experiment with *these* appliances. Though this experiment works only in theory, you can verify its results using smaller resistances.

This type of hookup is called a *series circuit.* All the appliances are connected together in a straight line or series. Old-fashioned Christmas tree lights used to be wired in this kind of circuit. If one of a string of lights burned out, the circuit was broken and all the lights went out.

In a series circuit, only one electrical path is available. Each coulomb of current goes through every part of the circuit. Therefore, the amperage is the same in all parts of the circuit. And the total resistance of the circuit will be the sum of all the individual resistances.

Notice the total resistance around the series circuit in figure 6·27:



PARALLEL CIRCUIT

6·28

Frying pan	10 ohms
Toaster	20 ohms
Refrigerator	30 ohms
	60 ohms

Using this information, can you now calculate the number of amps this imaginary circuit would take if it were actually plugged in? A little earlier, we used $\frac{\text{volts}}{\text{amps}} = \text{ohms}$. Therefore, it must also be true that amps $= \frac{\text{volts}}{\text{ohms}}$. However, in a series circuit, we must be sure to use the *total* resistance for the number of ohms. In this circuit:

$\frac{120 \text{ volts}}{60 \text{ ohms}} = 2$ amps of current.

If 2 amps move through all parts of this circuit, then how many volts would be measured across *each* appliance in the circuit?

Refrigerator:
30 ohms × 2 amps = 60 volts
Toaster:
20 ohms × 2 amps = 40 volts
Frying pan:
10 ohms × 2 amps = 20 volts

Compare these voltages with the voltages when each appliance was in a separate circuit. The watts used by each of the appliances when connected in series to a 120-volt source would be computed this way:

Refrigerator:
60 volts × 2 amps = 120 watts
Toaster:
40 volts × 2 amps = 80 watts
Frying pan:
20 volts × 2 amps = 40 watts

However, the manufacturers of these appliances recommend that the refrigerator use 480 watts, the toaster 720 watts, and the frying pan 1440 watts to work properly. Thus, in this series circuit, the refrigerator (at 120 watts) would be too warm; the toaster (at 80 watts) and the frying pan (at 40 watts), too cool. Also, if one of the appliances in the series were turned off, it would break the circuit so that none of the appliances could work. In a series circuit all parts must work or none work.

A more practical way to use several appliances with a single voltage source is shown in figure 6·28. This is called a *parallel circuit* because each user is connected directly to the outlet. Notice how many volts are available to each user in parallel. How many amps go through each user?

$$\text{Refrigerator: } \frac{120 \text{ volts}}{30 \text{ ohms}} = 4 \text{ amps}$$

$$\text{Toaster: } \frac{120 \text{ volts}}{20 \text{ ohms}} = 6 \text{ amps}$$

$$\text{Frying pan: } \frac{120 \text{ volts}}{10 \text{ ohms}} = 12 \text{ amps}$$

Compare the amperages of the appliances in parallel with their amperages in series. Notice that in a parallel circuit the greatest number of amps takes the path of least resistance in ohms. The effect of attaching appliances in parallel is that they work as though each appliance were on a separate circuit. The energy per second (watts) used by each appliance when connected in parallel as in figure 6·28 can be computed:

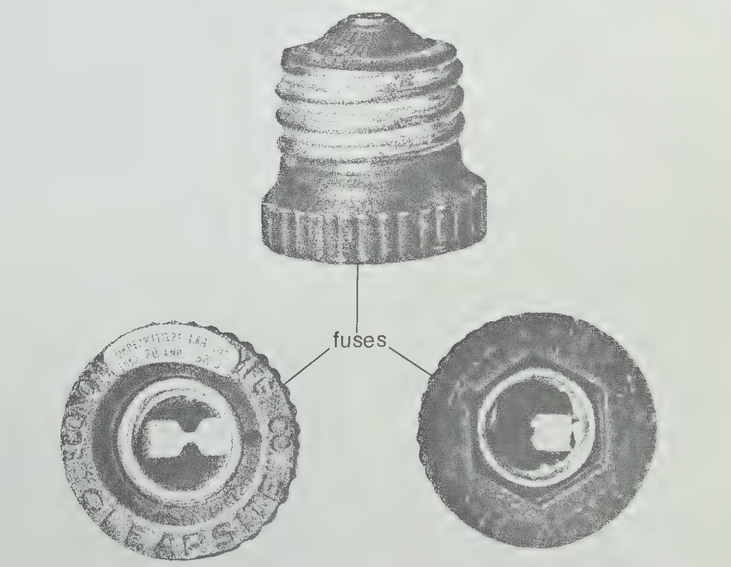
Refrigerator:
120 volts × 4 amps = 480 watts
Toaster:
120 volts × 6 amps = 720 watts
Frying pan:
120 volts × 12 amps = 1440 watts

Compare these wattage values with those recommended by the manufacturer (figure 6·26). Now the refrigerator, toaster, and frying pan will all perform as they should.

CAUTION: Appliances attached in parallel draw current off the line as they need it. Connecting too many appliances *in parallel* will therefore cause too many amps to pass through the house wires to the plug. Excess amperage can overheat the wires and cause a fire.

Appliances in your home and in your school are attached in parallel. Therefore, safety devices as shown in figures 6·29 and 6·30 are put into the circuit to break the path for electricity if too many amps are moving through the wires. Fuses and circuit breakers are such safety devices.

Fuses contain wire made of metal that melts at low temperatures. The thickness of the wire is varied to control the number of amps that can pass through a fuse before the wire overheats and melts.



6·29

When the amperage through the circuit is greater than the fuse was built to carry, the wire melts. The circuit is broken, and you must replace the fuse to complete the circuit again. If the circuit is still carrying too many amps, the wire in the new fuse will melt. Some people have "solved" this problem by putting a penny in the fuse box. This dangerous practice removes an important safety device and can lead to the house wiring getting so hot that it causes a fire.

Circuit breakers are more practical safety devices than fuses. The circuit breaker is an automatic switch. The switch is controlled by a mechanism which is usually magnetic. When the amperage passes the specified value, a magnet becomes strong enough to attract the contacts away from each other.

The main advantage of the circuit breaker is that it can be reset by hand. When the circuit breaker is open, you need only go to the circuit-breaker box and close it. Since it will reopen when the circuit is overloaded, and you cannot put a penny in it, you must correct the overload to complete the circuit. Thus a circuit breaker is safer as well as more convenient than a fuse.

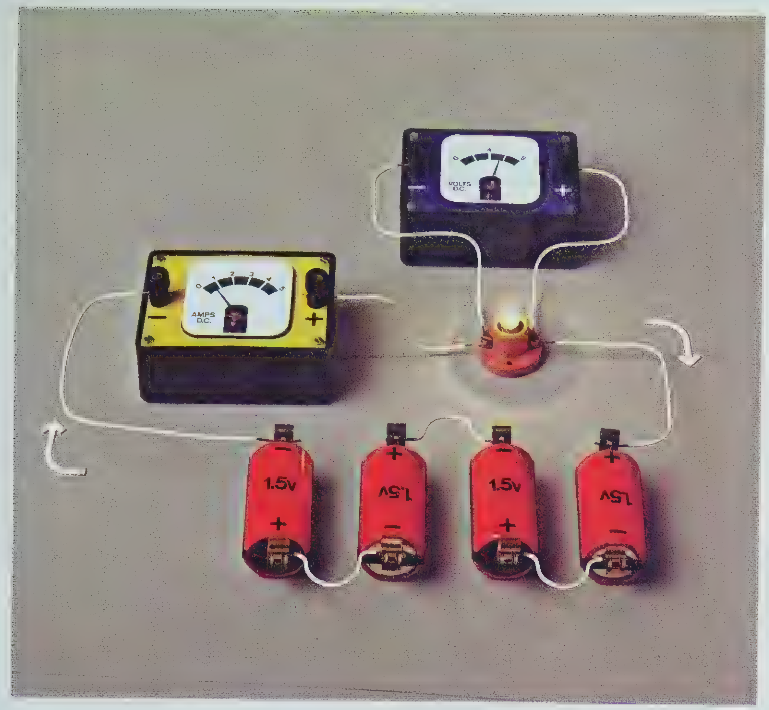
6·30 Circuit breaker

Batteries in series and parallel

You have seen that the amount of energy per second going through a group of appliances differs according to how they are wired together. Do wattage differences also occur when you connect electricity *sources* (batteries) in different ways?

In figure 6·31 there are two sets of four 1½-volt batteries, one set wired in series and the other in parallel. An identical lamp has been placed in each circuit. Is the lamp wired to the first set of batteries brighter or dimmer than the one wired to the second set?

Which method of wiring is supplying more volts? By multiplying the volts by the amps for the lamp in each circuit, you can determine which lamp is using more watts. Which set of batteries do you think will keep the lamp lighted longer? (Hint: A battery furnishing a current at a steady rate of ½ amp will last longer than an identical one supplying a steady 1-amp current.)



6·31a Batteries in series

TEST YOURSELF

1. *Describe the difference between the path electricity takes through a series and a parallel circuit.*
2. *What happens to the amperage in a parallel circuit as more appliances are plugged in?*
3. *How does a fuse differ from a circuit breaker in the way it stops a current?*
4. *Why should you not replace a fuse with a penny?*
5. *Will two 9-volt batteries wired in series keep a transistor radio running as long as two identical batteries wired in parallel?*

6·31b Batteries in parallel

A history of electric lighting

6·33 Edison's study, Edison National Historic Site, West Orange, N. J.

The Shining Lights

The interesting past of the ordinary light bulb

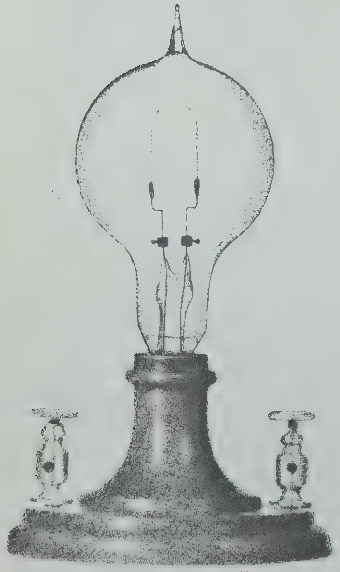
A small group of men stood watching anxiously as two of their co-workers were preparing an experiment. Then one of the two experimenters stood on an elevated platform and began pouring liquid through a series of tubes and valves. This, he pointed out, was a way to pump most of the air out of an odd-shaped glass bulb and to keep a semi-vacuum inside the bulb.

The men who were gathered in this crude laboratory stared at the glass bulb. The room was lit only by two flickering kerosene lamps hung on the wall. Many bulky storage batteries, like the ones in today's automobiles, stood connected in series in one corner. The second experimenter picked up the two wires connected to the batteries and touched them to metal posts at the base of the glass bulb. A thin carbon thread which had been almost invisible inside the bulb began to glow. It glowed with such a white-hot brilliance that the kerosene lamps seemed to dim. The men gathered in the drafty laboratory that October night in 1879 turned their heads or shielded their eyes from the fiercely glowing thread. But they also cheered the inventor of the first practical electric light bulb, Thomas Alva Edison!

Before Edison, many had attempted to make an electric lamp whose filament would get hot enough to produce usable light without quickly melting or burning up.

In 1802, Sir Humphrey Davy of England showed that strips of platinum or other metals could be heated to glowing, or incandescence, by passing an electrical current through them. These strips or filaments gave off light, but for a very short time before they melted.

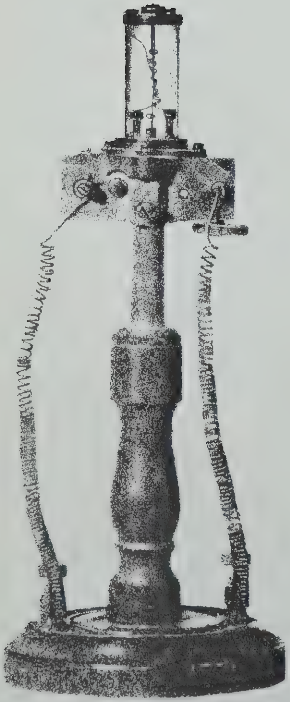
The first patent for an incandescent lamp, the ordinary light bulb, was awarded in 1841, 38 years before Edison's invention. The lamp consisted of an almost airless glass sphere. Inside it, powdered charcoal bridged a gap between two platinum wires or filaments. Light was produced by passing an electric current through the filaments. This current heated the charcoal until it glowed. The invention was impractical because the glass sphere quickly became black and the lamp burned out in a very short time.


6·32 Edison's first light bulb

It was Sir Joseph Wilson Swan of England who paved the way for Edison's invention of a practical incandescent lamp. As early as 1850, Swan made carbon filaments from paper. Since these burned out after a few minutes of use, he continued his search. By 1875 he was using cotton thread which he "carbonized" by treatment with sulfuric acid. And he mounted the filament in glass vacuum bulbs, as Edison was to do a few years later. But even after many years of patient work, Swan still was not successful. His lamps did not glow brightly enough or for a long enough time. It is interesting, though, that an early English electric company was known as the Edison and Swan Lighting Company.

Edison tried many materials including Swan's filaments and agreed with Swan that a carbon filament was the best. At first Edison had made filaments by heating cotton thread in an oven until it turned to charcoal. Because these filaments broke too easily, Edison turned to charred bamboo strips. Lamps with the bamboo filaments burned brightly and lasted for about one hour. Edison was able to prevent the bamboo filament from burning up by removing more air from the bulb than Swan had. He could do this because his vacuum pumps were much improved over Swan's.

By varying the electrical energy source and the filament in the airless glass bulb, Edison improved his original electric light bulb until it glowed for 40 hours. But he continued to experiment. Finally, he invented a carbon filament of such diameter and length that it lasted from 600 to 800 hours when mounted in a vacuum and connected to a 110-volt source. Edison's lamp gave enough light at reasonable cost to compete with existing gas lights. The new lamps lit up the 1893 World's Fair in Chicago and began to change the world. But the victory was not total. A more easily prepared filament was still needed.


6·34 An early light bulb with an experimental filament

Researchers tried and discarded many processes. Someone developed a process of squirting carbon filaments from a paste. This process gave more uniform filaments than the carbonized threads or charred bamboo strips. Another found that preheating the carbon filament, while a light bulb was being made, enabled it to withstand long periods of intense heat. However, it was the metal, tungsten, which became the most useful filament material. Tungsten is a tough, durable metal with a very high melting temperature that can be drawn out into very thin, strong wire. It also "burns" three or four times longer than a carbon filament.

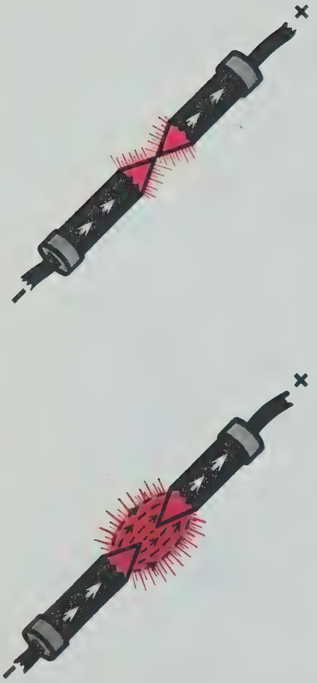
Because each tungsten filament can be made the same as every other one, lamp engineers can make bulbs that give light at specific rates when used with specific electricity sources. The early carbon filaments were not alike and there was no need for standard sources. So the standard light bulbs speeded the development of standard electricity sources—like the power plants that provide electricity for homes and offices.

Even with all these improvements, research did not stop. In 1922, an American physicist named Irving Langmuir (lang′mūr) was working in the research laboratories of the General Electric Company. He found that filling the light bulb with a gas such as nitrogen or argon helps prevent the tungsten filament from vaporizing, as it does in a vacuum. These gases provide a protective atmosphere around the glowing filament. They are used rather than air because the filament would burn in air. Another process which slows down the vaporization of the filament was invented about this same time. This process involves winding the filament into tiny coils. (Note: Examine an unfrosted light bulb with a magnifying lens and try to see these tiny coils in the filament.) Because of these two improvements, you can operate filaments at higher temperatures for longer periods of time and get more light for your money than was possible with the earlier light bulb.

The carbon arc—another oldtimer

Another form of electric lighting, just as old as the incandescent lamp, is the carbon arc. When two carbon rods connected to opposite poles of an electricity source touch, they form a complete circuit. Electricity passing through the carbon rods causes them to get very hot. The heat turns some of the carbon into vapor. If the carbon rods are then moved a short distance apart, the carbon vapor acts as a link in the circuit. So the electricity continues to flow. As the

6·35 Early light bulbs with experimental filaments



6·36 Carbon arc lamp

electricity keeps flowing through the carbon rods, it continues heating them. Since the electrical resistance of the carbon decreases as the rods get hotter, more and more electricity flows through the rods and their tips become extremely hot. They produce a glow so brilliant that it can damage yours eyes if you look directly at it.

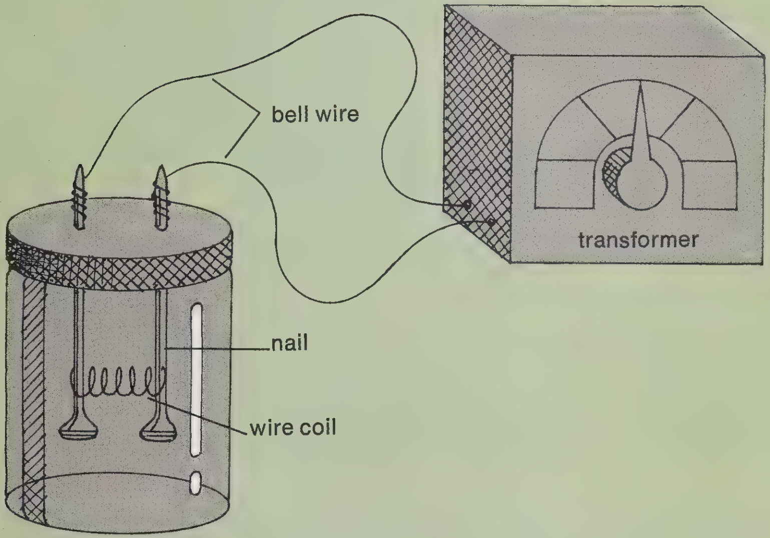
At first, the carbon arc was used for street lighting and the lighting of large areas such as baseball and football fields. Now, many of these are lit by incandescent lamps or gas discharge lamps (see below). Carbon arcs are now used, for the most part, in searchlights where a small, intense source is of great advantage. They also are used in the motion-picture industry as light sources for both photography and projection.

Color, color everywhere

A special kind of electric lamp has been used since the 1890's where colored light of low intensity is preferred, as in sign lighting. These lamps operate on the principle that certain gases at low pressures give off colored light when electricity passes through them. The color of light depends on the gas used. Neon gas gives red light, mercury vapor gives bluish green, carbon dioxide gives white, xenon gives bluish white, and helium gives purplish white. Long, thin lamps filled with one or more of these gases at low pressures are called gas discharge lamps.

Each gas discharge lamp has an *electrode* or metallic terminal at each end. An electric current passes from one electrode, through the gas-filled tube, to the other electrode. Usually such a lamp needs a much higher voltage to start than it needs to keep glowing. So a special starting device is used to give the gas or vapor an initial jolt of electrical energy. After this initial drain, the lamp is an efficient user of electricity.

ON YOUR OWN



6·37

Incandescent lamp

You can make an incandescent lamp with these materials:

1	wide-mouthed jar
1	cork, cardboard, or rubber jar cover
2	5-cm (2-in) nails
1	transformer from an electric train or car set (It should have a built-in circuit breaker or fuse. DO NOT use any other kind of transformer.)
2	25-cm (10-in) lengths of #20 insulated copper bell wire
1	25-cm (10-in) length of braided copper lamp wire

Clay, putty, or chewing gum
Tape

PROCEDURE: Put the nails through the cover of the jar, about 2 1/2 cm (1 in) apart. Use clay, putty, or chewing gum to hold the nails in position. Strip 1 cm (about 1/2 in) of insulation from the ends of the lengths of bell wire. Attach the wires to the transformer as shown in figure 6·37. Now pull six thin strands from the braided lamp wire. Twist two and three strands together to make filaments of varying thicknesses. Coil a single-strand filament by wrapping it around a toothpick. Coil the other filaments in the same way. Attach the single strand filament to the nails as in figure 6·37. Now attach the wires from the transformer to the tops of the nails. Plug in the transformer. Add electrical energy slowly by turning the transformer switch until the wire coil glows. Then *quickly* turn off the current by using the transformer switch or by unplugging the transformer. If you keep the current going through the coil for any length of time, you may burn out your transformer.

Try the 2- and 3-strand thicknesses of wire filament. Which glows the brightest? With the least power? If there is any iron picture wire available at home, you might use it to make iron filaments. Compare the iron filaments with the copper ones.

Chapter 7: Electricity and Magnetism

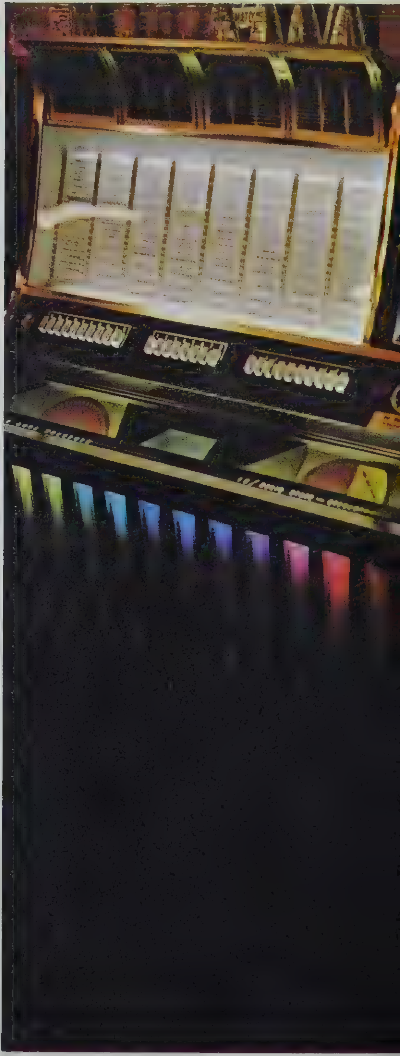
7

The coin-operated automatic record player that some people call a "jukebox" would not work without magnets. When you drop a coin in the slot, a magnetic device checks the coin to see if it is real. Then a magnetic device switches on the selection buttons. The push buttons are connected to more magnetic devices which hold the selections you've punched.

Now the selector motor, containing magnets, is turned on. A mechanical "picker" runs back and forth, scanning all the numbers, until it stops at your selection. Another magnet-containing motor moves the arm which pulls the record from its slot and places it on the turntable. The turntable is driven by yet another motor that has magnets in it.

Finally, the tone arm comes down. Vibrations are picked up and changed to electrical signals. These are amplified and sent to speakers. There are magnets in the speakers which actually produce the sound by vibrating the air.

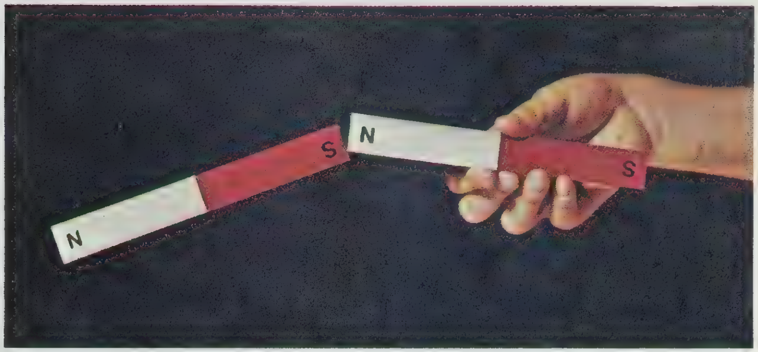
There are unseen magnets in very many of the electrical devices you use. This chapter is about those magnets and how they are related to electricity.



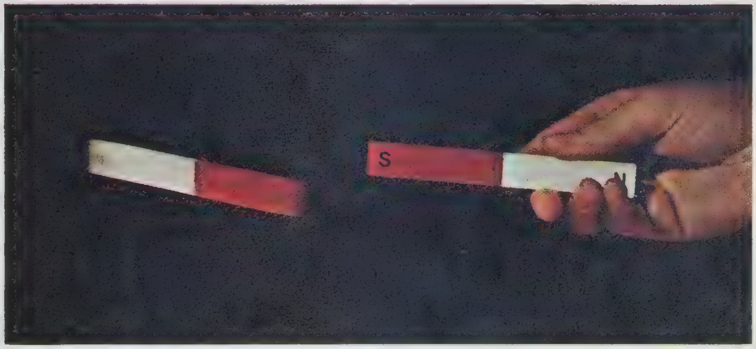
A piece of magnetized iron, the bar magnet, can illustrate several main properties of all magnets. If you hang a bar magnet by a string, it tends to line up in a certain direction. Even if you give it a spin, when the magnet comes to rest again, it will point the same way as before. For this reason, we say a magnet has *poles.*

One end of the suspended magnet is always attracted toward the north *geographic* pole of the earth. The other end, of course, points toward the south geographic pole. We label the end of the magnet that points in a northerly direction the N-pole, or north pole. The other end of the magnet is, then, the S-pole, or south pole.

Suppose you bring the N-pole of a second bar magnet close to the S-pole of your suspended magnet (figure 7·2). The S-pole of the suspended magnet will move toward the N-pole of the second magnet in your hand. The N-pole of the suspended magnet will swing away. Now suppose you bring the S-pole of a bar magnet close to the S-pole of a suspended bar magnet. What will happen?



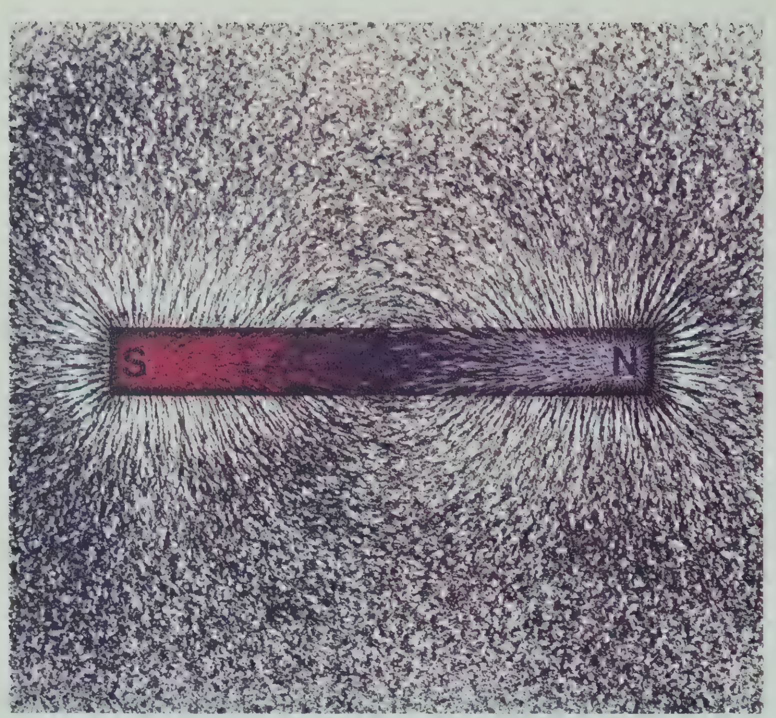
7·2 Opposite magnetic poles attract each other.



7·3 Like magnetic poles repel each other.

Like every magnet, the earth is surrounded by a magnetic field. This field is the space in which a magnet attracts iron objects and in which one magnet affects the actions of another. For example, the north pole of a suspended bar magnet does not have to touch the earth's south *magnetic* pole (north *geographic* pole) to swing toward it. In the same way, a bar magnet will attract iron filings before they touch its surface.

The magnetic field around a bar magnet can be located by sprinkling iron filings on a piece of paper over the magnet (figure 7·4). The iron filings form a pattern you could duplicate with pencil lines on another piece of paper. The

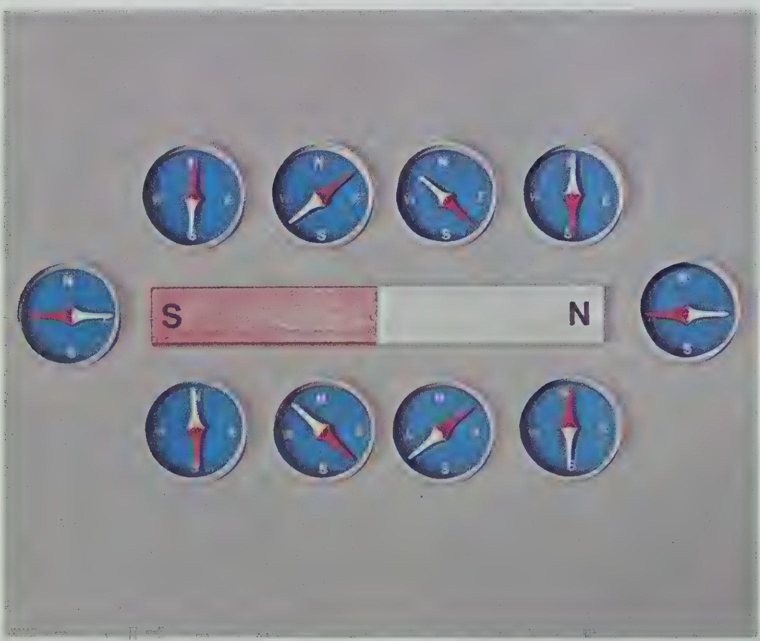


7·4

pencil lines would show the shape of the invisible magnetic field of that magnet.

There is another way to plot the field around a large magnet. The needle in a *magnetic compass,* which is really a type of bar magnet suspended over the earth, always lines up in the north-south direction of a magnetic field. So, you can use such a compass to plot a picture of a magnetic field like the one in figure 7·5. The picture is a record of the direction a compass needle pointed as the compass was moved to many positions around a large magnet. The more places you plot, the more detailed will be your map of the magnetic field. There is no limit to the number of lines you could draw (if your pencil point were thin enough).

In summary, every magnet has a magnetic field around it which can be displayed by drawing lines of its magnetic attraction for iron filings or a compass needle. The lines show the *direction* of the magnetic attraction at all positions around the magnet.



7·5 Compass needles are magnets. The compasses in these photographs have white N-poles and red S-poles.

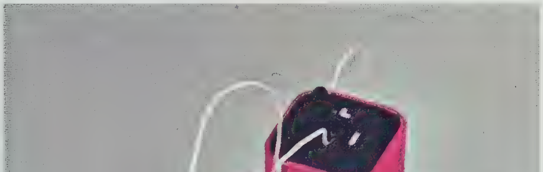
Magnets you can turn off

Magnets that can be turned on and off are very useful. You use this kind of magnet every time you use a telephone or press a doorbell. You can read about how these magnets are used in "Messages by Wire" on page 172. But first, let's look at how magnets can be turned on and off.

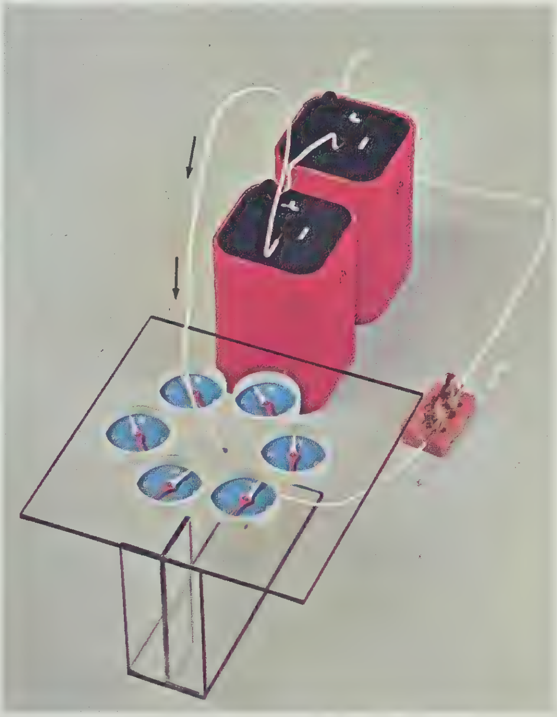
As you know, a compass needle will line itself up with the magnetic field of the earth —but only when no other stronger magnetic field is present. Thus, when a compass needle points in any other direction but geographic north, something with a magnetic field must be nearby.

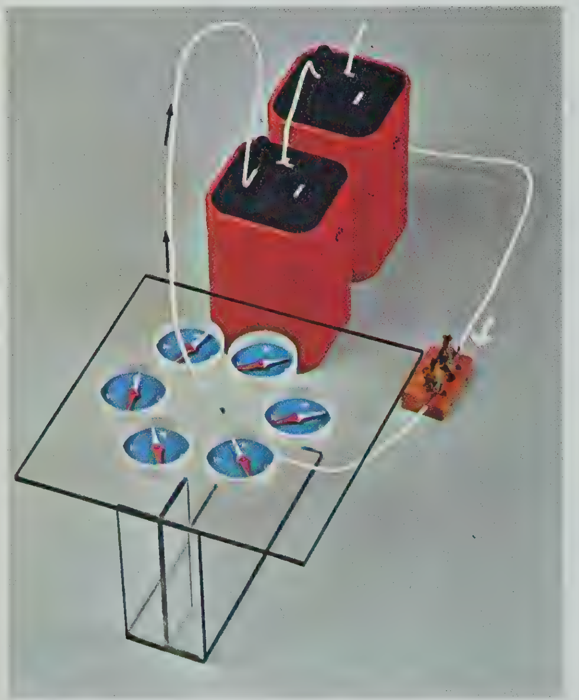
Figure 7·6a shows a straight section of wire surrounded by compasses on a flat surface. When the switch is closed, electricity moves through the wire. Study the photos for the results. What differences can you find among figures 7·6a, 7·6b, and 7·6c?

7·6a The switch is open. No electricity moves through the wire. Notice the direction of the compass needles. In what direction are they pointing?

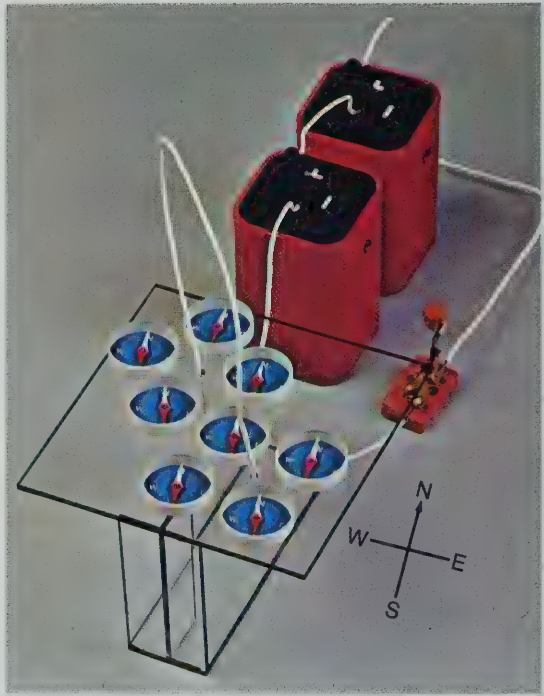


7·6b The switch is closed, completing the circuit. Note that the electricity flows from the negative to the positive terminal of the battery. Observe the direction of the compass needles.





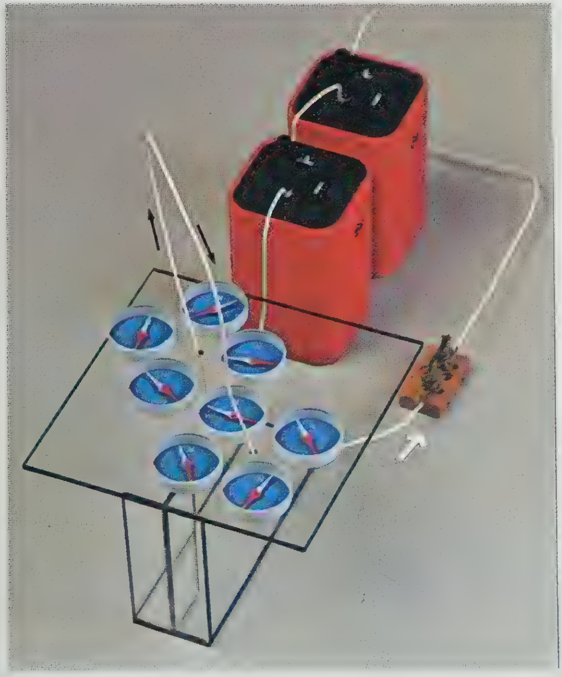
7·6c If the battery connections are reversed, the electricity will move around the circuit in the opposite direction. How does this change affect the magnetic field?



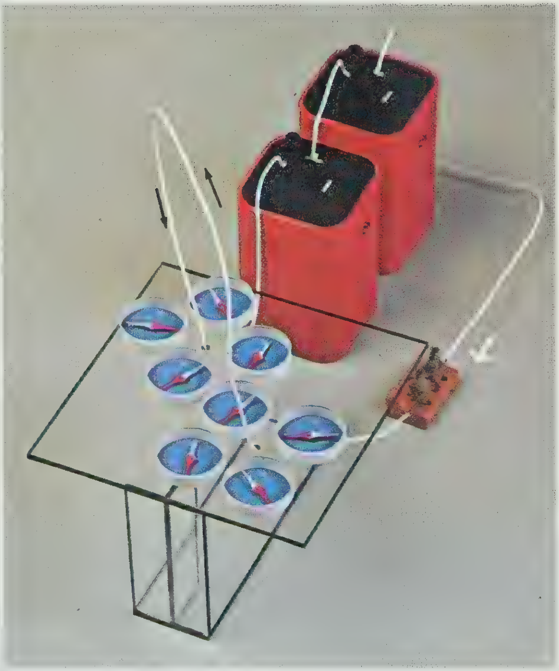
7·7a The switch is open, allowing no electricity to move through the wire. Notice the direction of the compass needles. Why are they all pointing in the same direction?

Figure 7·7 shows a wire loop surrounded by compasses in the same way as the straight wire in figure 7·6. Compare the compasses in figure 7·6 with those in figure 7·7. How does the magnetic field of a wire loop differ from that of a straight wire?

The magnetic field inside the wire loop is formed from the magnetic fields of the two sections of straight wire. Does the loop have a magnetic field when there is no current? What happens to the magnetic field of the wire loop when the direction of the current is reversed?



7·7b The switch is closed, making a complete circuit. Note the direction of the compass needles. (Remember that the electricity moves from the negative to the positive terminal of the battery.)



7·7c The battery connections are reversed. The electricity moves through the circuit in the opposite direction. How does this affect the magnetic field?

TEST YOURSELF

1. *What is a magnetic compass?*
2. *How can you use a magnetic compass to find the N-pole of a bar magnet?*
3. *To which of the earth's magnetic poles will the S-pole of a suspended bar magnet point?*
4. *What happens if you bring "like" magnetic poles near one another?*
5. *What happens if you put a compass next to a current-carrying wire?*
6. *What happens to the needle of a compass when you put it in the center of a current-carrying wire loop?*
7. *How does reversing the direction of the current through a wire affect a compass next to that wire?*

Contributions of Galvani, Volta, Oersted, and Ampère to electricity

Frog Legs and Other Things

Physics was a very busy science in the early 1700's. Physicists were experimenting with new theories about astronomy and about the laws of motion and matter. But only a few physicists were concerned with electricity. There had been few new discoveries about electricity since ancient Greek times. More important, at this time, electricity was available only as a static charge. The charge was on an amber rod that had been rubbed with fur, or in Leyden jars that could be used to collect and store larger amounts of charge (page 132). This static electricity was very unmanageable, since it could only be discharged all at once. It was not very useful, and it was likely to cause painful shocks. Many physicists were content to stay ignorant about it.

By the middle of the eighteenth century, electricity had taken on a new interest. Ben Franklin, DuFay, and Van Musschenbroek were some of the early experimenters (page 131). But there were many others. One was an Italian anatomy professor named Luigi Galvani (gäl vä′nē). Galvani became interested in electricity when he saw some lifeless frog legs move as they were touched with a metal scalpel. He thought he had discovered an "animal electricity" which was the cause of movement in animal muscles. It turned out he was wrong, but his idea stirred up a lot of interest. In particular, it aroused the curiosity of another Italian who was working with static electricity.

An observant Italian

In 1780, when he heard of Galvani's experiment, Alessandro Volta was already a well-known physicist. As a child, he had been curious about many natural mysteries. When he was sixteen, a friend set him up with some simple equipment for physics experiments. Two years later he was writing about his experiments to a respected French physicist. And by the time he was twenty-four, he wrote his first major scholarly paper. In it, he stated that all electrical effects were related to an electrical force, similar to the gravitational force that governs falling objects.

When Volta heard about Galvani's "animal electricity" he was very skeptical. Galvani thought that the electricity he saw was generated in the frog legs. But Volta was a more careful experimenter. He knew that Galvani had had many kinds of equipment and materials on his worktable. Maybe some of the materials, and not "animal electricity," had caused the frog legs to twitch.

So Volta started the tedious task of examining these other factors. Finally, he found that zinc (like the coating of Galvani's worktable) and iron (like Galvani's scalpel) would produce an electrical current if a suitable conductor is between them. The salty solutions contained in the frog legs proved an ideal conductor.

Thus Volta corrected Galvani's conclusion. The frog legs twitched because they were *conducting* electricity, not generating it.

7·8 Volta demonstrating his voltaic cell for Napoleon.

Volta finished his experiments along this line. But he also had gotten a new idea. He had found two metals that generated enough electricity to power some small animal muscles. Could some combination of metals be found to generate electricity for bigger jobs?

He put aside this problem for many years. Then in 1800, Volta wrote a letter describing his idea for a battery, an arrangement of metal plates to produce a steady source of electricity.

That same year he built his "voltaic pile." It was so named because he piled on top of each other a copper plate, then a brine-soaked cloth, then a zinc plate, then another brine-soaked cloth, and so on. When the two end plates were connected, a steady flow of electricity was generated by a chemical reaction of the metals and the brine solution. At last physicists had a continuous source of electricity for their experiments!

Volta, who was 55 at the time, did no more basic research. But he had made certain that electricity would be available for the work of others. In this way, Volta made possible the discovery of the relationship between electricity and magnetism.

7·9 Early voltaic cells

A "lucky" Dane

Hans Christian Oersted (ėr′sted) never thought of himself as a great scientist, and he never wrote bold papers as Volta had. His name is in history because he was a careful observer—and because he had a bit of good luck.

He was born in Denmark, the son of an apothecary, a man who makes up medicines and simple chemical products. His family thought he would follow his father's profession. But Hans showed a bent for physics and also for teaching. So he became a good, if not brilliant, physics professor.

Professor Oersted kept a compass on his desk to demonstrate to his students the magnetism of the earth and of magnetic materials. He also had a small voltaic pile for experiments with electricity. One day in 1819, the compass happened to be directly under a wire from the pile. And when Oersted connected the pile in a circuit, the compass needle, a magnet, moved. That is all. That was the event that made Hans Oersted's career.

After class, Oersted pondered what he had observed. He checked and rechecked to make sure that the electricity in the wire was really what had moved the compass needle. In July of 1820, after months of cautious experiment, Oersted wrote a paper on his discovery: how an electric current affects magnets.

Although fame and honors came to him, Oersted continued his teaching as before. He left the experimenting to the many assistants who came to work for him. It was up to another physicist, hundreds of miles away in France, to discover the real importance of Oersted's observation.

A thinking Frenchman

André Marie Ampère's (äm′pãr) biography is almost the opposite of Oersted's life story. He grew up during the stormy years of the French Revolution. And when he was 18 years old, Ampère saw his father beheaded by the revolutionaries. Ampère's first wife died of tuberculosis, and his second marriage ended unhappily after two years. Perhaps because of this turbulent life, Ampère developed a passion for order in his work.

Ampère's sense of order gave him an idea as soon as he read Oersted's paper. After a few days of intense experimenting, he had proven what he suspected. A wire carrying a current not only exerts force on a compass needle—it also exerts a force on another electrified wire. This discovery was very important to Ampère. It showed him that a wire carrying a current generates its own magnetic field. He hurried and published his paper within one week of reading Oersted's paper!

Later, Ampère worked out a mathematical relationship for this "electromagnetic effect." In it he related the amount of current, the length of wire, the force generated, and the direction of the magnetic field. This relationship is called Ampère's Law. It was very important to physicists because it explained a great many electrical effects in a very simple form. It also raised a question for everyone interested in electricity. Can a magnetic field generate an electric current?

Many people worked on that question, including Ampère himself. In 1825, after discouraging experiments, he declared it could not be done. He was probably just saying that he was getting older, and the young physicists would have to take over the quest.

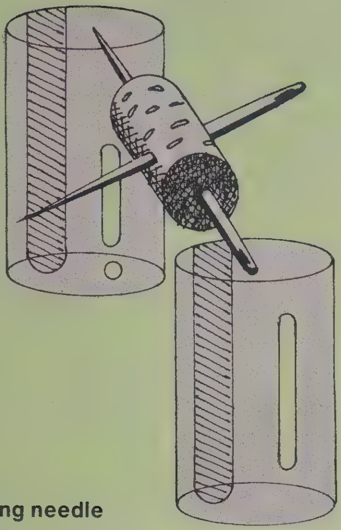
On a new threshold

Scientists were now on the threshold of harnessing a new source of energy. Three people had led to that threshold, each contributing in his own way.

They had different talents. Volta was the great experimentalist, knowing both what to look for and how to look. Oersted used hard work and careful observation to prepare his find for the use of others. And Ampère was the brilliant analyst. Experimental discoveries—his own or those of others—were only raw material for him. He searched for the basic relationships.

You may have some of these scientific talents, too. In fact, think about that problem of making electricity from magnetism. All you have to do is putter around with magnets and wires for a while, because that is exactly how it was first done. However, you will need to know more before you can putter around effectively.

ON YOUR OWN



7·10

The dipping needle

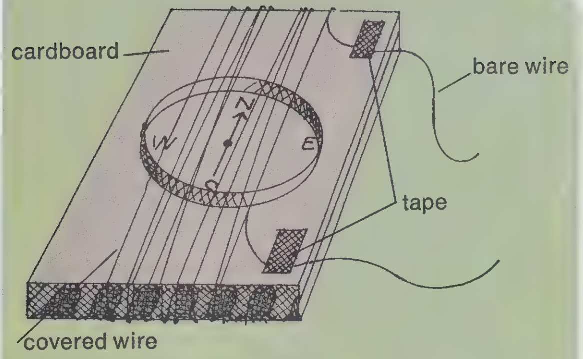
You can demonstrate a dipping needle as a "magic" trick. To make one, you will need the following materials:

2 steel needles
1 cork or small piece of Styrofoam
1 magnet
2 water glasses

PROCEDURE: Carefully push the needles through the center of the cork or piece of Styrofoam at right angles to each other as in figure 7·10. Put the glasses on a table slightly less than a needle-length apart. Rest the ends of the first needle on the glasses and balance the second needle so it is level and pointing north and south. Tell your friends that through some magic powers, which only you are able to summon up, you can "shift" part of the weight to the sharp end of the needle. You then proceed to magnetize the balanced needle by stroking it lengthwise in one direction with the magnet.

The north-south needle will now dip a little, as if one end were slightly heavier than the other. The dipping needle shows that the earth's magnetic field does not run parallel to the surface of the earth. The needle is attracted directly toward the earth's north *geographic* (south magnetic) pole, as it would be if the curving surface of the earth was not there.

ON YOUR OWN



7·11

Simple compass galvanoscope

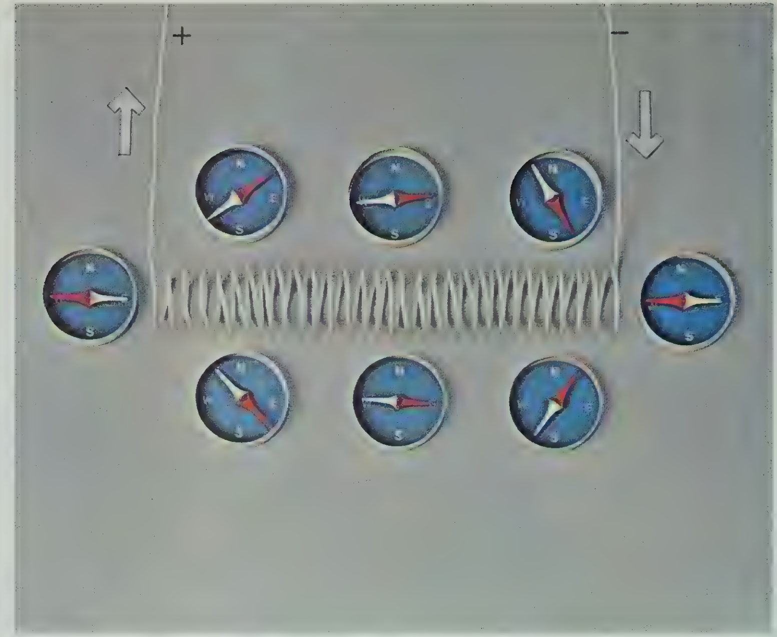
You can make your own device to detect a weak electric current. It's called a galvanoscope. It is simple to make one from these materials:

1 pocket compass
1 8-cm (3-in) square of corrugated cardboard
1 10-meter (11-yd) length of #20 insulated bell wire or #24 insulated magnet wire
Glue
Tape

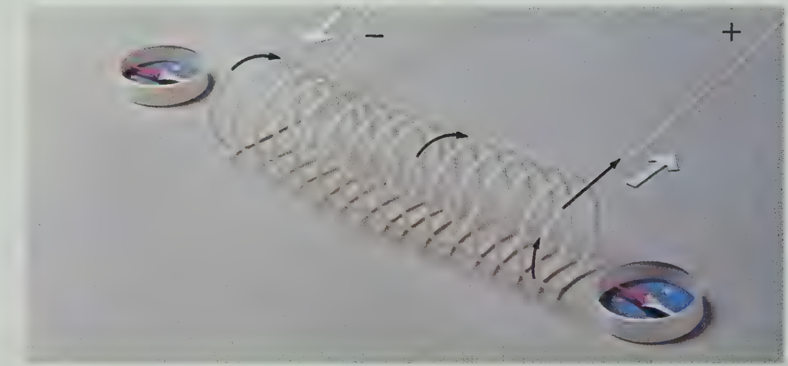
PROCEDURE: Glue the compass into the center of the cardboard square. Wind 50 turns of wire around the compass and cardboard in a north-south direction. Tape the ends of the wire, one to each side of the cardboard as in figure 7·11. Now you can easily attach your wires to a current source.

Try your galvanoscope by attaching a 1 1/2 volt flashlight battery to the wires. Notice what happens to the position of the compass needle. What will happen if you reverse the connections to the battery? Keep this instrument to use in the activities following chapter 8.

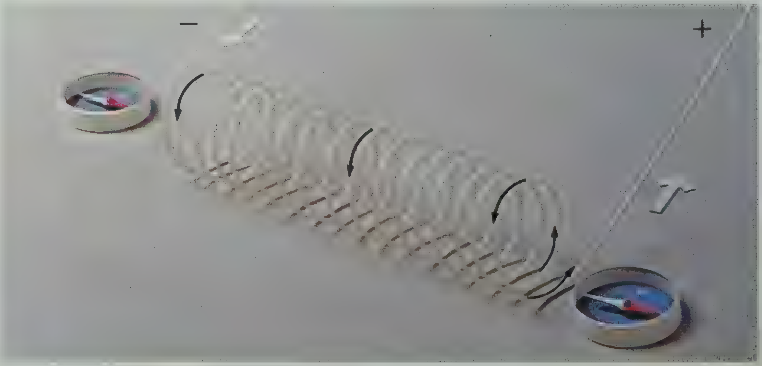
What if you coil the wire?



7·12



7·13a



7·13b

An interesting thing happens when you coil a wire into several loops and connect the ends of the wire to a battery (figure 7·12). Look at the needles of the compasses around the coil when a current is passing through the wire. How do they compare with the direction of the compass needles placed around a single wire loop (figure 7·7, page 158)? around a bar magnet (figure 7·5, page 156)? Which end of the coil in figure 7·12 behaves like the N-pole of a bar magnet? How do you know that?

You remember that reversing the direction of the current through a wire loop caused the magnetic field to reverse its direction. The same thing will happen if you reverse the direction of the current through a wire coil.

But there is a second way in which you can reverse the direction of the magnetic field of a current-carrying coil. The coil in figure 7·13a is wound in a clockwise direction and the coil in figure 7·13b is wound in a counterclockwise direction. Although the electricity is entering at the same end of each coil, the compass

7·12 and 7·13 Compass needles are magnets. The compasses in these photographs have white N-poles and red S-poles.

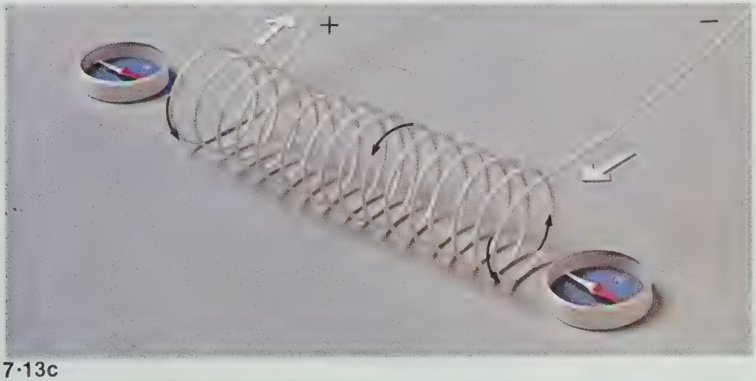
Electricity enters the coil from the negative terminal of the battery. It returns to the positive terminal to complete the circuit.

needles are pointing in opposite directions. The magnetic field of the coil in figure 7·13a is therefore in the reverse direction to the magnetic field of the coil in 7·13b, because the coil is wound in the opposite direction.

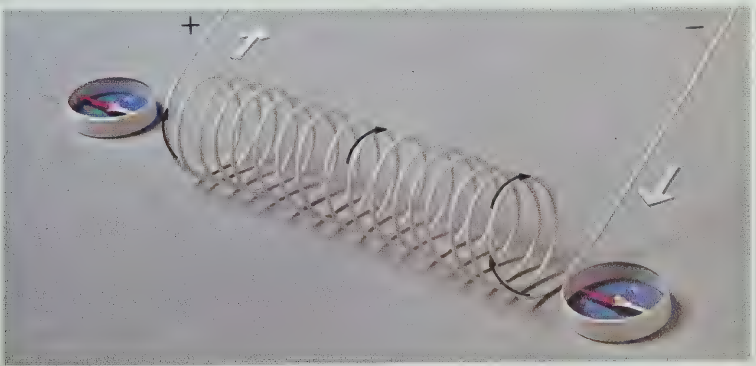
The more usual method of reversing a magnetic field in a coil, however, is to reverse the current. The coil in figure 7·13c is wound the same way as that in 7·13a, but the attachments to the battery terminals have been reversed. Now compare the coil in figure 7·13d to the one in 7·13b. How are they alike and how are they different?

There is a simple way to find which end of a coil of wire will act like the N-pole of a bar magnet. First you must find where the pulses of electricity are entering the coil. The pulses move from the negative terminal of a source to the positive terminal. Then put your *left* hand around the coil with your fingers bent in the direction in which the pulses are flowing through the wire. Hold your thumb out straight. Your thumb will be pointing to the end of the coil that acts like the N-pole of a bar magnet.

When you coiled the wire, you made an *electromagnet*—a current-carrying coil of wire with a magnetic field similar to that of a bar magnet. But suppose you open the switch. There will be no current traveling through the coil and, like the wire loop, it will have no magnetic field.



7·13c



7·13d

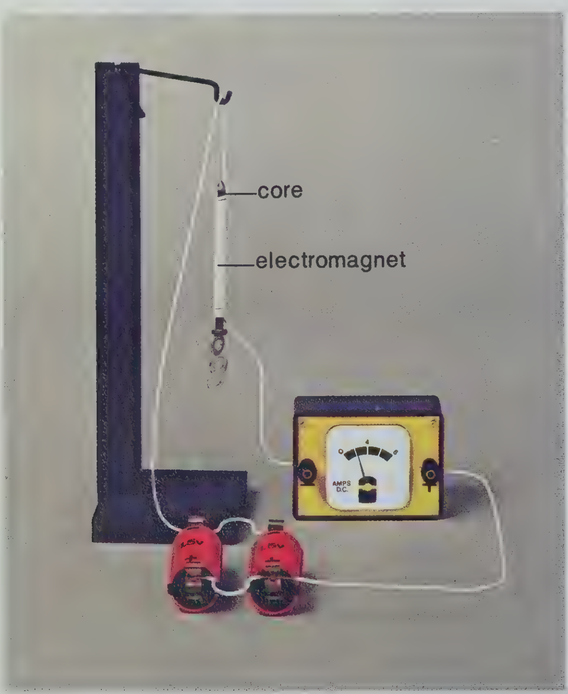
The strength of electromagnets

You can compare the strength of electromagnets in the same way as you would compare the strength of bar magnets. Simply compare the amount of weight they will lift.

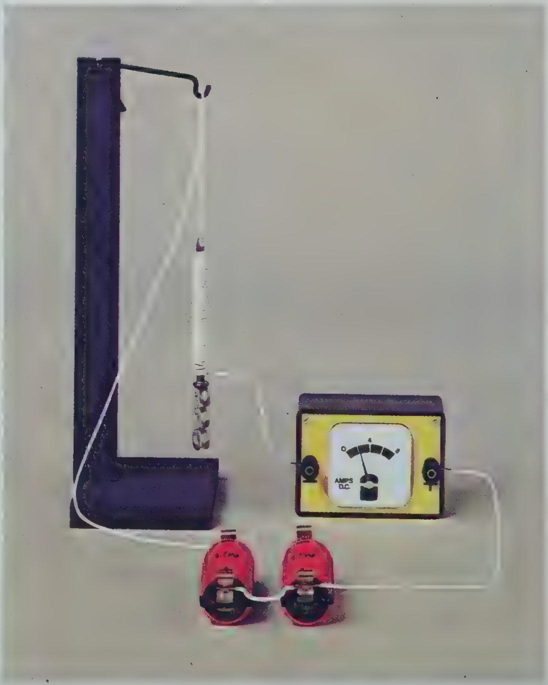
Each coil in the photos is wound around an *iron core*. As current passes through the coil, the iron core becomes magnetic. It thus strengthens the electromagnet. When the current is off, the coil and core have no magnetic field.

Look at the electromagnets in figures 7·14, 7·15, and 7·16. How are the magnets in the first set different? How does the number of coils affect the amount of weight an electromagnet can lift? Compare the weights lifted by the first electromagnet in the first set with the weights lifted by the electromagnets in the second set. They all have the same number of coils, but they are not lifting the same weight.

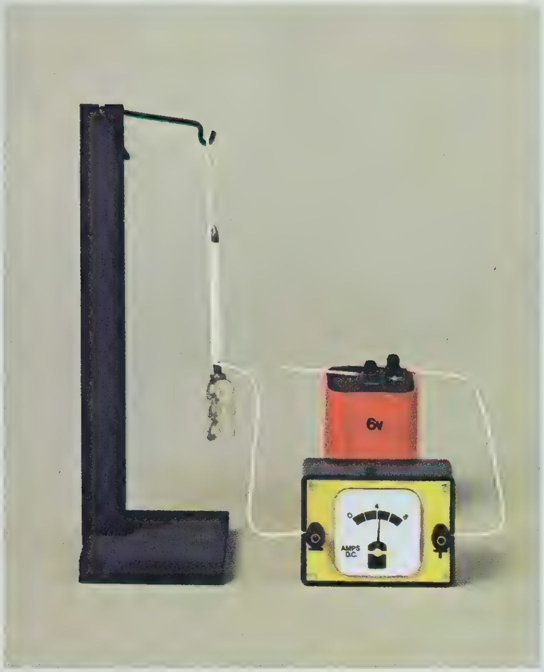
Now compare the electromagnets in the third set. Do they lift as much weight as the first electromagnet in the first set? Which electromagnet can lift the most weight? The electromagnets in figures 7·14, 7·15, and 7·16 were strengthened in three ways. All electromagnets can be made stronger in the same three ways. Can you name them?



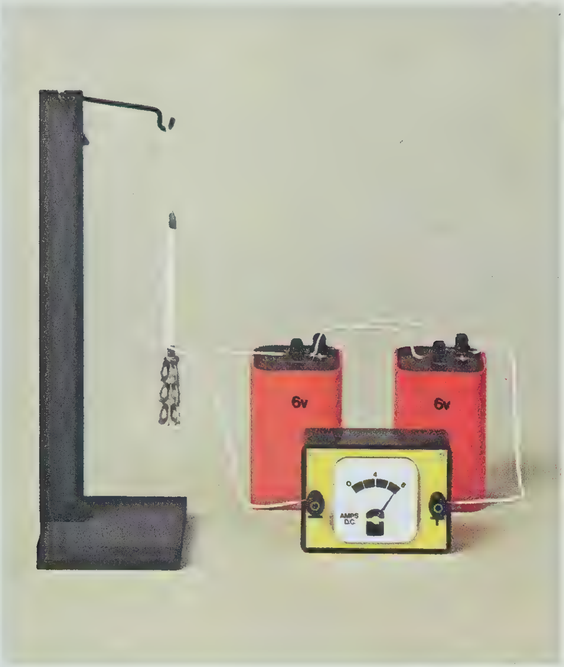
7·14a Electromagnet with *50 coils* and 2 amps current, lifting 3 weights.



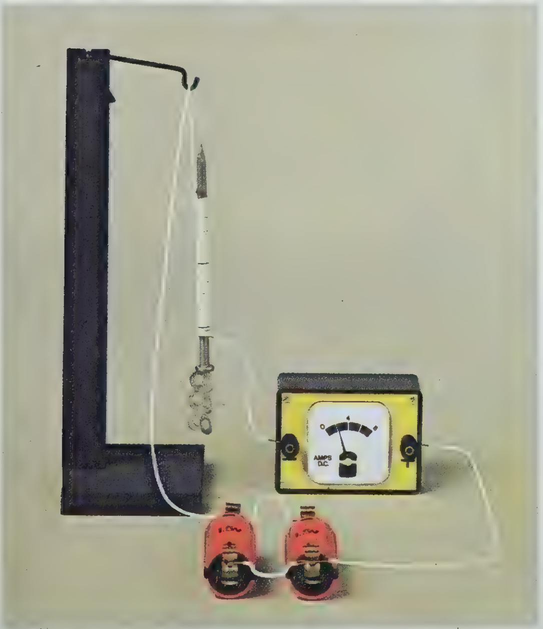
7·14b Electromagnet with *100 coils* and 2 amps current, lifting 6 weights.



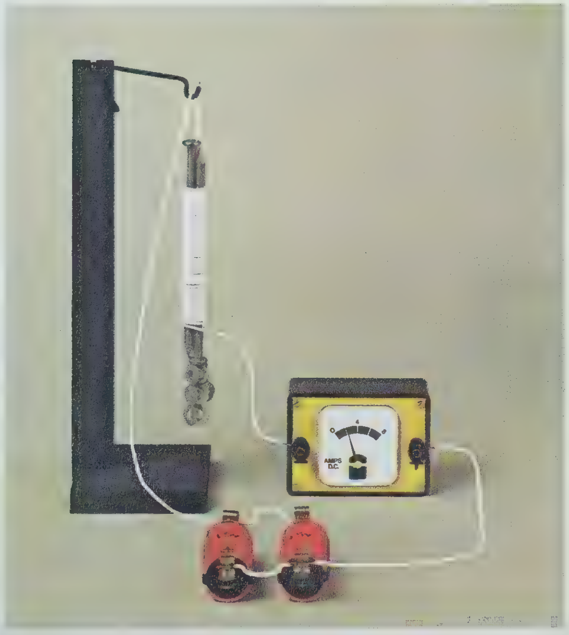
7·15a Electromagnet with 50 coils and *4 amps current*, lifting 6 weights.



7·15b Electromagnet with 50 coils and *8 amps current*, lifting 12 weights.



7·16a Electromagnet with *thicker nail as core*, 50 coils, and 2 amps current, lifting 6 weights.



7·16b Electromagnet with *2 thicker nails as core*, 50 coils, and 2 amps current, lifting 12 weights.

Electricity produces magnetism, so magnetism should be able to produce electricity.

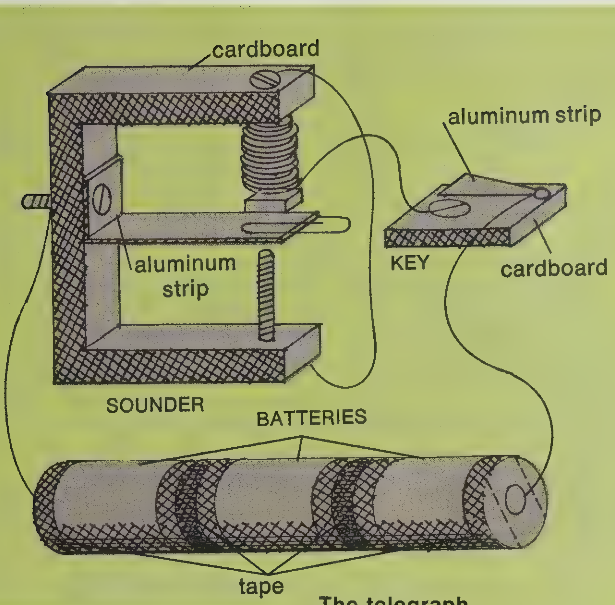
If you move a bar magnet into a coil of wire attached to a milliammeter (an instrument for measuring a 0.001-amp current), the milliammeter needle will move (figure 7·17). Electric current is induced, or produced, in the coil of wire while the magnet is moving. But nothing happens when the magnet sits motionless inside the coil. There has to be motion between the magnet and the coil of wire in order for the milliammeter needle to move.

The magnetic field strength is different at different points around a bar magnet. If you thrust a bar magnet into a coil of wire, the magnetic field strength at points within the coil changes as different parts of the magnet pass by. If the strength of a magnetic field inside a coil of wire changes rapidly, an electric current is induced in the wire. Moving either the coil or the bar magnet so that the magnetic field strength within the coil changes generates an electric current through the wires of the coil.

7·17

7·18

ON YOUR OWN



7·19

The telegraph

You can build a telegraph from these materials:

Corrugated cardboard
1 aluminum pan from a frozen pie or dinner
2 1-cm (1/2-in) screws (or unpainted thumbtacks)
2 5-cm (2-in) iron bolts
1 nut to fit one of the bolts
1 paper clip
3 1 1/2-volt D batteries
1 10-meter (11-yd) length of #20 insulated bell wire
Masking tape

PROCEDURE: 1) *The key:* Cut two 22-cm (9-in) by 1-cm (1/2-in) strips off the aluminum pan. Fold the strips in half. Tape together enough 8-cm (3-in) square pieces of cardboard to make a block 2-cm (3/4-in) high. Attach an aluminum strip across the block with a small screw (figure 7·19). Put another small screw into the other end of the block so that it will be hit when you press down on the aluminum strip.

2) *The sounder*: Fold a 23-cm (9-in) by 8-cm (3-in) piece of cardboard into a support as shown. Gently push one bolt through the top of the support and one through the bottom. Put the nut on the top bolt, so that it is even with the free end of the bolt.

Bend the remaining aluminum strip into an L. Attach it to the side of the support with a small screw. Put a paper clip on the free end of the strip so that it touches the bottom bolt. Coil three layers of wire around the top bolt to make it an electromagnet.

Wire the key, the sounder, and the batteries into a circuit as shown. To complete the circuit, push the aluminum strip on the key against the screw. The electromagnet is turned on. It pulls the paper clip away from the bolt, breaking the circuit. The electromagnet then turns off. The strip falls against the lower bolt, completing the circuit again. This cycle repeats itself, causing a clicking sound, as long as the key is against the screw.

If the wires are long enough, you can keep the key in one room and the sounder and batteries in another. And if a friend also makes a set, you can exchange messages.

TEST YOURSELF

1. *In what ways can you reverse the direction of the magnetic field of a current-carrying coil?*
2. *What happens to an electromagnet when you turn off the electricity?*
3. *How can you find the N-pole of an electromagnet?*
4. *Name three ways to make an electromagnet stronger.*
5. *Which will lift a heavier load, an electromagnet with 50 coils or one with 50 coils and an iron core if both have the same current?*
6. *Which will lift a heavier load, an electromagnet with 50 coils and an 8-amp current or one with 50 coils and a 2-amp current?*
7. *What happens if you move a bar magnet back and forth inside a coil of wire?*

Users of the principles of electromagnetism: the telegraph and the telephone

Messages by Wire

Throughout history, people have always tried to come up with better and better ways of communicating over large distances. Some of the ways have been quite clever.

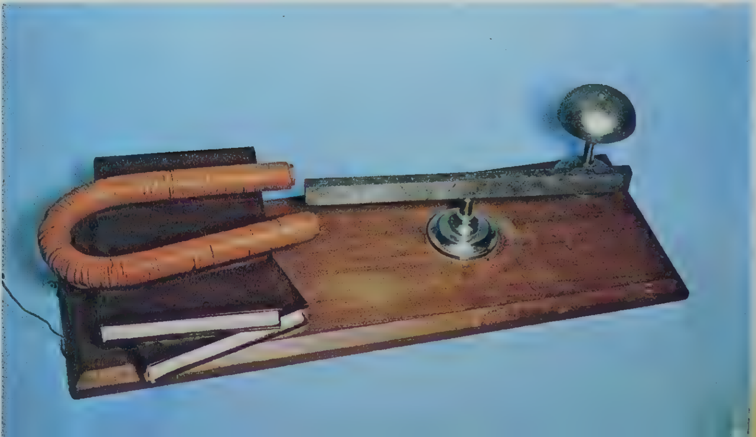
One of the most primitive means of communication involved beating on a hollow log with sticks. The resulting sound was carried through the air to a distant listener who interpreted the beats he or she heard. Some South American Indians improved upon this form of communication a long time ago. They found that sound travels faster and farther through water than through air. So they set up sending and receiving stations along rivers. They used partly submerged hollow logs both as *transmitters* (or senders) and as *receivers*.

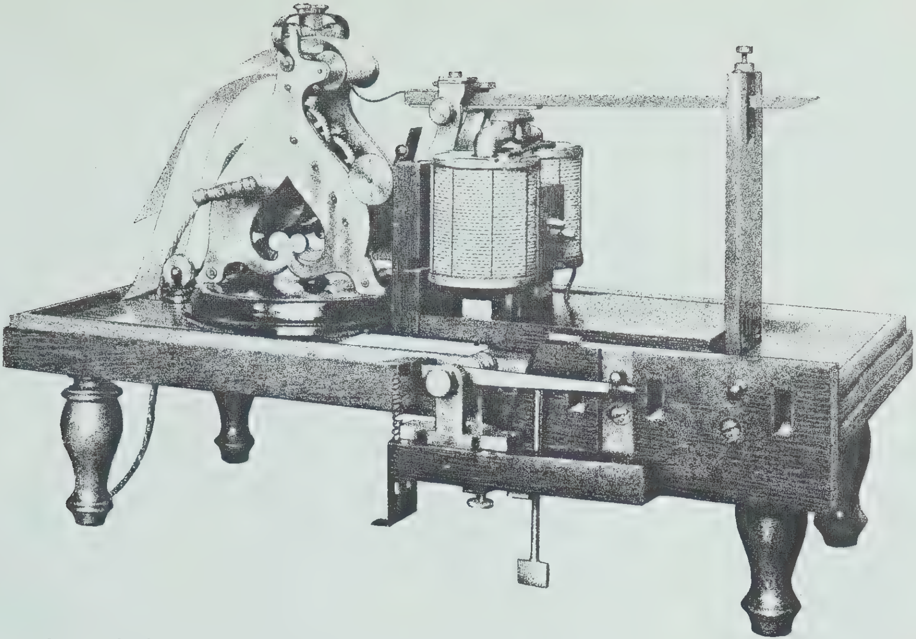
In the early "civilized" world, people found a number of ways to send written messages: by stagecoach, horseback riders, ships' captains, and runners. In general, however, communication methods did not change much until the 1800's. It was then that the telegraph was invented.

The clicker

In the 1830's Joseph Henry, an American, was experimenting with the lifting and pulling effects of electromagnets. He used a setup like the one in figure 7·20. When Henry closed the switch, the electromagnet attracted the movable iron bar, which pulled against

7·20





the spring and struck the gong. What Henry really had before him was an electric bell. But it had all the parts necessary for a practical communications system.

In 1839, Samuel F. B. Morse, a brilliant American painter, used the basic parts of Henry's electric bell in his invention, the *telegraph.* It's the telegraph receiver that is very similar to the electric bell.

The person sending a telegraph message clicks a small, hand-operated electric switch called a *key*. When he lowers the key, he completes an electrical path between the transmitter, the receiver, and the power source (figure 7·21). At the receiving end, there are two electromagnets. When the circuit is closed (by the key), these electromagnets pull a spring-held striker against a sounding block. You can then hear a click. When the telegrapher releases the key, the circuit is broken and the striker is released at the receiving end. This produces a click of a slightly different pitch. The strike-sound is a "click." The release-sound is more of a "ka." Thus, a telegraph message consists of combinations of clicks, sort of a click-ka. . . . click-ka. . . .click-ka. The dots and dashes of telegraph codes are determined by the relative lengths of time between the "click" and the "ka."

Each telegraph station has a key and a sounder. Each key is connected so that it can close and open the electrical paths to sounders in distant stations.

7·21 Early Morse commercial telegraph. This telegraph wrote out code on a moving strip of paper. When the bar holding the stylus was attracted by the electromagnet, the stylus rose and made a mark on the paper. When the bar was released, the stylus fell away from the paper.

Sending words and music by wire

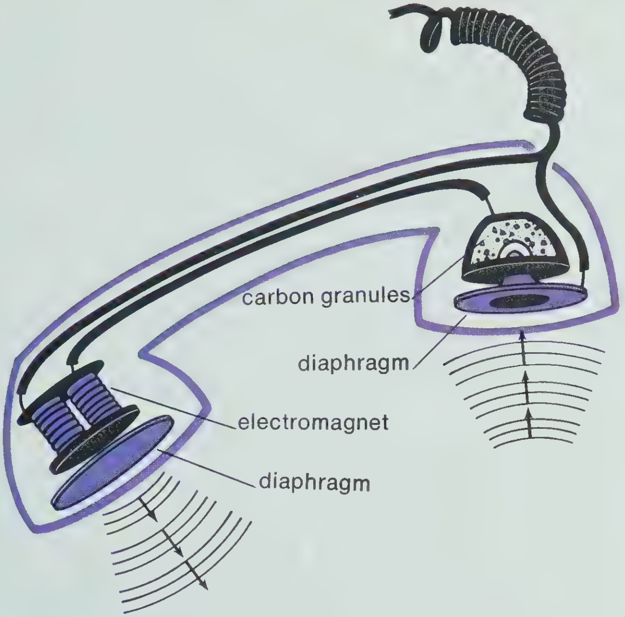
When the telegraph was invented it was a big step forward in communication. But, as you know, much more was to come.

We all think of the telephone today as a very common thing. But it wasn't always. When Alexander Graham Bell invented it in 1876, most people didn't even realize its value.

The basic parts of the telephone haven't changed much from those early days. Here's how Bell's model worked:

His telephone had a thin flexible metal disk attached to an iron rod near an electromagnet. Such a flexible disk is called a diaphragm. When Bell or his assistant spoke into their telephone, the diaphragm vibrated. This vibration moved the iron rod, causing tiny voltage changes in the electromagnet. These voltage changes were transmitted through a current-carrying wire to the receiver.

7·22 Early Bell telephones



7·23

7·24 Modern telephone

The receiver was just like the transmitter. But there, the process was reversed. The voltage changes made the diaphragm of the receiver vibrate. The diaphragm vibrations set up vibrations in the air. These vibrations were an approximate reproduction of the sounds spoken into the transmitter, similar enough so that one could usually identify the person speaking.

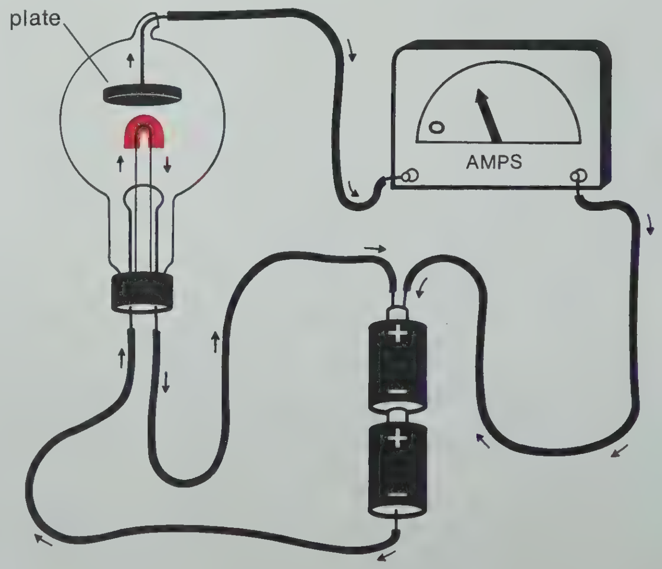
In the modern telephone there is a plastic diaphragm instead of a metal one. This plastic diaphragm is placed against packed grains of carbon instead of an iron rod. The speaker's voice causes the diaphragm alternately to compress and loosen the carbon grains behind it. This allows varying amounts of current to flow through the circuit between the transmitter and the receiver. Thus, the electromagnet at the receiving end vibrates in tune with the sounds formed miles away, at the other end of the wire. The diaphragm, vibrating with the electromagnet, sends the vibrations into the air. And what the listener hears sounds very much like the speaker's voice.

Vacuum tubes and transistors: mainstays of modern communications

Broken Circuits that Conduct

Oops!

In his early experiments with the electric light bulb, Thomas Edison made a discovery which he could not explain. Inside one of his light bulbs, he had sealed a metal plate near the filament. He connected the metal plate, through an ammeter, to the positive terminal of a battery (figure 7·25). He then closed the circuit to which the bulb's filament was connected. As the filament heated up, the ammeter needle moved. This movement showed that electricity was flowing from the heated filament to the metal plate. But the metal plate and the filament were not touching, and inside the bulb was a vacuum. Somehow an electric current was flowing from the filament to the metal plate across a vacuum! Edison recorded these observations in his notebook. But he continued his light-bulb experiments without trying to explain them.



7·25

An explanation

These observations, which became known as the "Edison effect," intrigued other scientists and inventors. Fourteen years later, in 1897, Sir J. J. Thomson made a discovery which could be used to explain the Edison effect. Thomson had found evidence for the existence of tiny negatively charged particles of matter which we call *electrons.* In the Edison effect, electrons escape from a bulb's filament as it is heated. The metal plate attached to the positive terminal of a battery is nearby. Since the electrons have a negative charge and can move through a vacuum, they are attracted to the metal plate. This completes a circuit, and the ammeter (connected to the plate) shows an electric current.

Putting it to work

In 1904, Ambrose Fleming, an Englishman, was experimenting with some of Edison's bulbs that had the extra metal plate inside. First he repeated Edison's experiment. He also found that current would flow from a heated, negative filament to a plate attached to the positive terminal of a battery (figure 7·26a). Then he reversed the direction of the current. He attached the plate to the negative terminal of several batteries (figure 7·26b). He found that *no* electricity will flow from the filament to the plate when it is attached in that way. And because the plate is not heated, no electrons will flow from the plate to the filament. In this situation, the bulb acts like an open circuit.

The heated filament and plate in a vacuum bulb which allows electricity to flow in only one direction was called "Fleming's valve." Today it is known as a vacuum tube. Because this type of vacuum tube contains two main electrodes (or terminals) it is known as a *diode* (*di-* meaning two). Older radio and television sets, tape and record players, calculators, and computers rely upon diodes to allow electricity to pass through certain branches of their circuits in only one direction.

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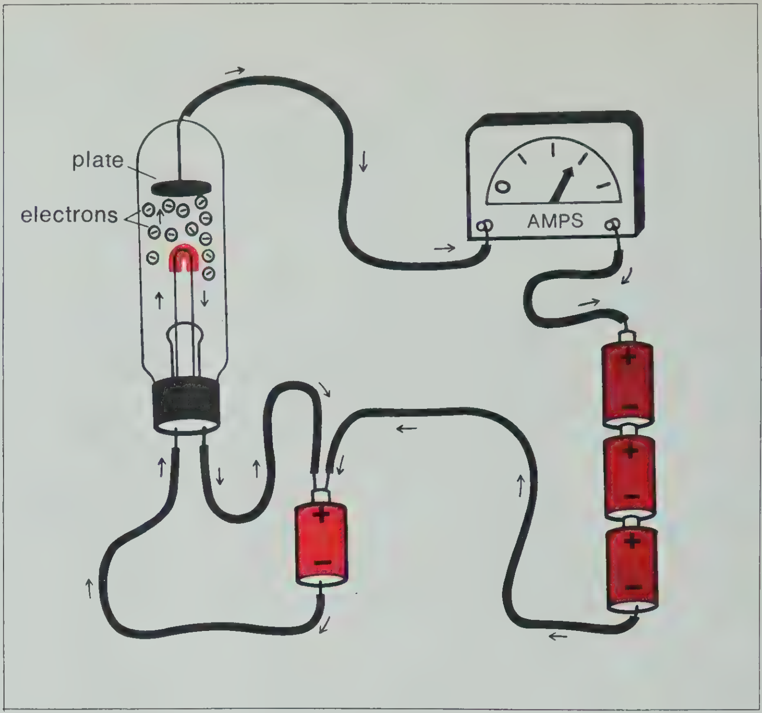
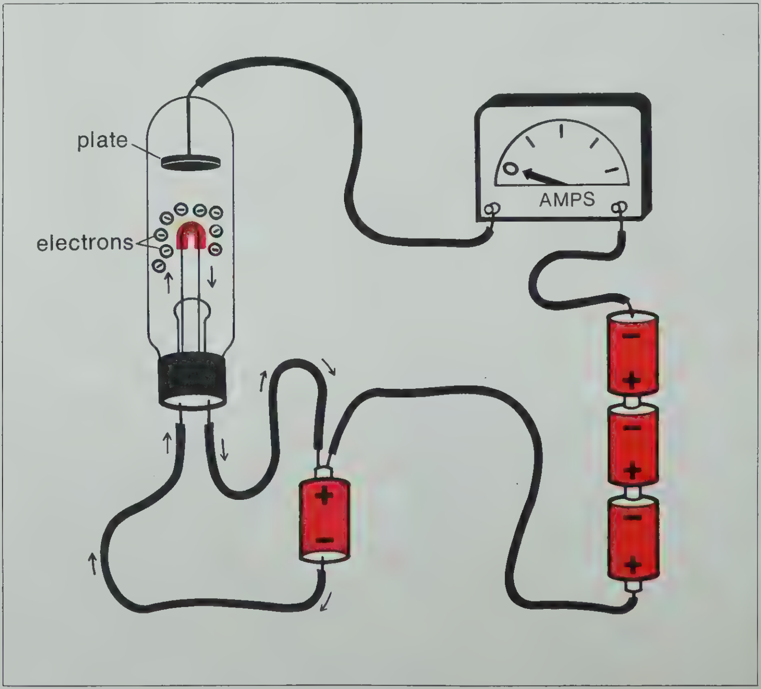
7·26a Diode with current flowing from heated negative filament to plate attached to positive terminal of battery.



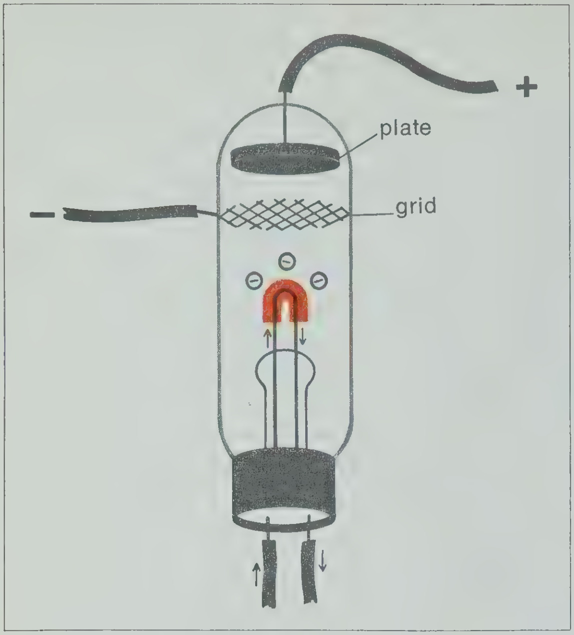
7·26b Diode in which no current is flowing from filament to plate since plate is attached to negative terminal of battery.



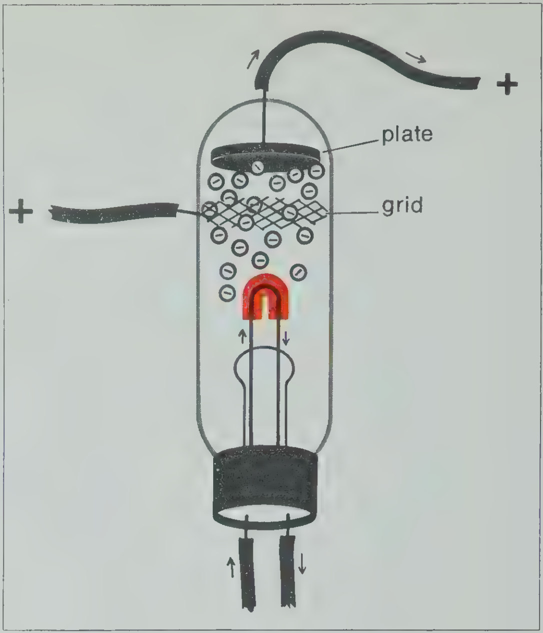
Another invention

The "Electronic Age" began in 1906 when the American physicist Lee DeForest added a third electrode to Fleming's diode. The third electrode was a piece of wire screen between the filament and the plate. DeForest called the third electrode a *grid.* The whole invention was called a *triode*.

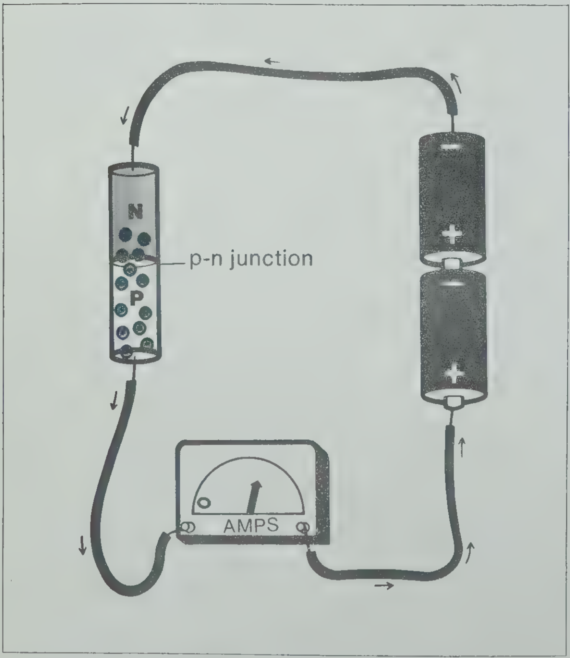
The grid in the triode allows a very delicate control of the flow of electrons. When the grid has no charge, the electron-losing filament and the electron-gaining plate work as they would in a diode. When the grid is much more negative than the filament, it repels *all* of the electrons from the electron-losing filament (figure 7·27a). So *no* electric current flows through the plate-filament circuit. When the grid is slightly more negative than the filament, it repels some of the electrons from the heated electron-losing filament. In this case, a small electric current flows through the plate-filament circuit. In the rare instances when the grid is positive with respect to the filament, it helps the plate pull electrons from the electron-losing filament. A larger current flows through the plate-filament circuit than in any of the other cases (figure 7·27b). Scientists did not realize the importance of DeForest's triode immediately. But DeForest did. He suggested that his triode would make it possible to transmit the human voice across the Atlantic Ocean in a few years. He was publicly accused of being "absurd and deliberately misleading." Of course, he was falsely accused. The development of the radio and television depended on the triode. (See the essay on "Signals Without Wires.") The development of many other electric devices also depended on triodes and the more complex vacuum tubes that came later.



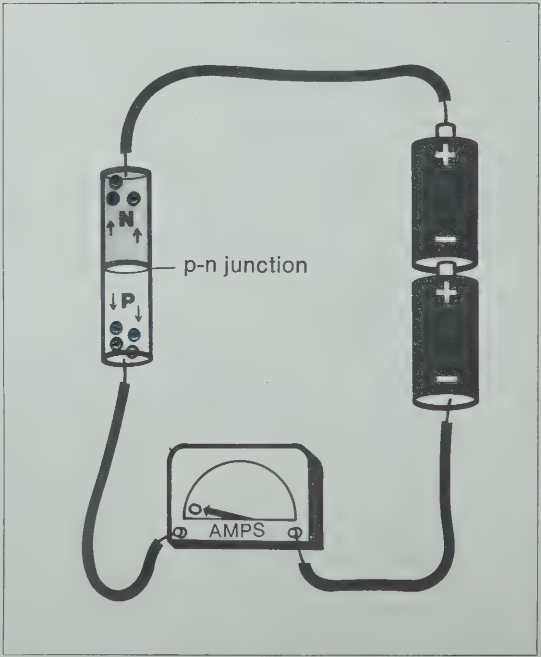
7·27a Triode with no current flowing in the plate-filament circuit.



7·27b Triode with current flowing through the plate-filament circuit.



7·28a Semiconductor diode with current flowing across the p-n junction.



7·28b Semiconductor diode with attachments to the power source reversed. No current is flowing across the p-n junction.

A better way

Vacuum tubes get hot because the filament must be heated to produce the Edison effect. You might have noticed the red glow of vacuum-tube filaments when they are in operation. Many vacuum tubes, such as the ones used in some computers, must be operated in air-conditioned rooms.

The loss of electrical energy in the form of heat and the need for special cooling devices make vacuum tubes expensive to operate. Now there is a solution to this problem. Small crystals are made which work much like vacuum tubes. The tiny artificial crystals are called *semiconductors.* There are semiconductor diodes and triodes. They are used in all electronic devices that carry the label *solid state.*

Semiconductors conduct electricity because of the unique properties of the crystalline solids which are used to make them. When a very small amount of one type of impurity is added to the crystal, it has the effect of adding excess electrons to the crystal. When a very small amount of a second type of impurity is added to the same, pure crystal, it has the reverse effect of making the crystal "electron-poor." A semiconductor diode is made up of a pure crystal wafer, half of which has been treated to make it "electron-rich" while the other half has been treated to make it "electron-poor." The "electron-rich" half of the wafer is called an *n-type* (or negative) semiconductor. The "electron-poor" half is called a *p-type* (or positive). The sharply defined border between the two halves of the wafer is called a *p-n junction* (figure 7·28).

You can send a current through a semiconductor diode in only one direction. The n-type wafer half should be attached to the negative pole of a power source. The p-type half should be attached to the positive pole (figure 7·28a). Electrons from the power source

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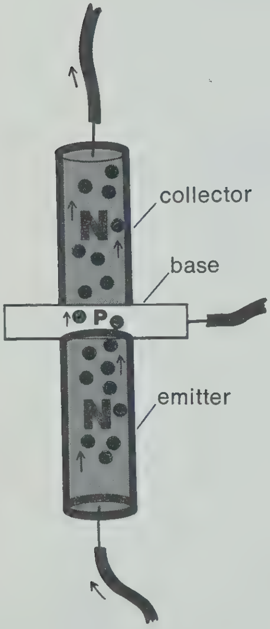
enter the n-type half of the wafer. The p-type half attracts the electrons from the n-type half. Thus a current flows across the p-n junction, always from n to p. When the attachments to the power source are reversed, as in figure 7•28b, the p-type half of the wafer receives electrons from the power source. It becomes negative and repels the electrons in the n-type half. So almost no current flows across the p-n junction.



7•29 Semiconductor triode or transistor

The *transistor,* or semiconductor triode, is a crystal sandwich made up of a p-type crystal wafer between two n-type crystal wafers (n-p-n). Or it could also have an n-type crystal wafer between two p-type wafers (figure 7•29). In each kind of transistor, one of the outer wafers (either n-type or p-type) is connected to the negative terminal of a power source and becomes the *emitter,* or electron sender. The other outer wafer is positively charged and becomes the electron *collector.* The center wafer (or *base*) acts like the grid of a vacuum tube. The base receives changing current from another power source, such as a radio receiving antenna. The changing current in the base controls the flow of current through the collector-emitter circuit.

Semiconductor transistors and diodes have improved the efficiency of many things such as radios, television, and computers. Because of semiconductors, many of these things can also be made much more compact and cooler operating.

The principles of radio and television

Signals Without Wires

Scientists in the late 1800's learned how to make an electric current flow back and forth through a circuit many times per second. Heinrich Hertz in Germany found that when he sent the rapidly alternating current into an *antenna* which consists of little more than a long bare wire, the antenna gave off *radio waves* (radiant energy of very long wavelength that cannot be detected by the human eye). Hertz detected these waves with another antenna.

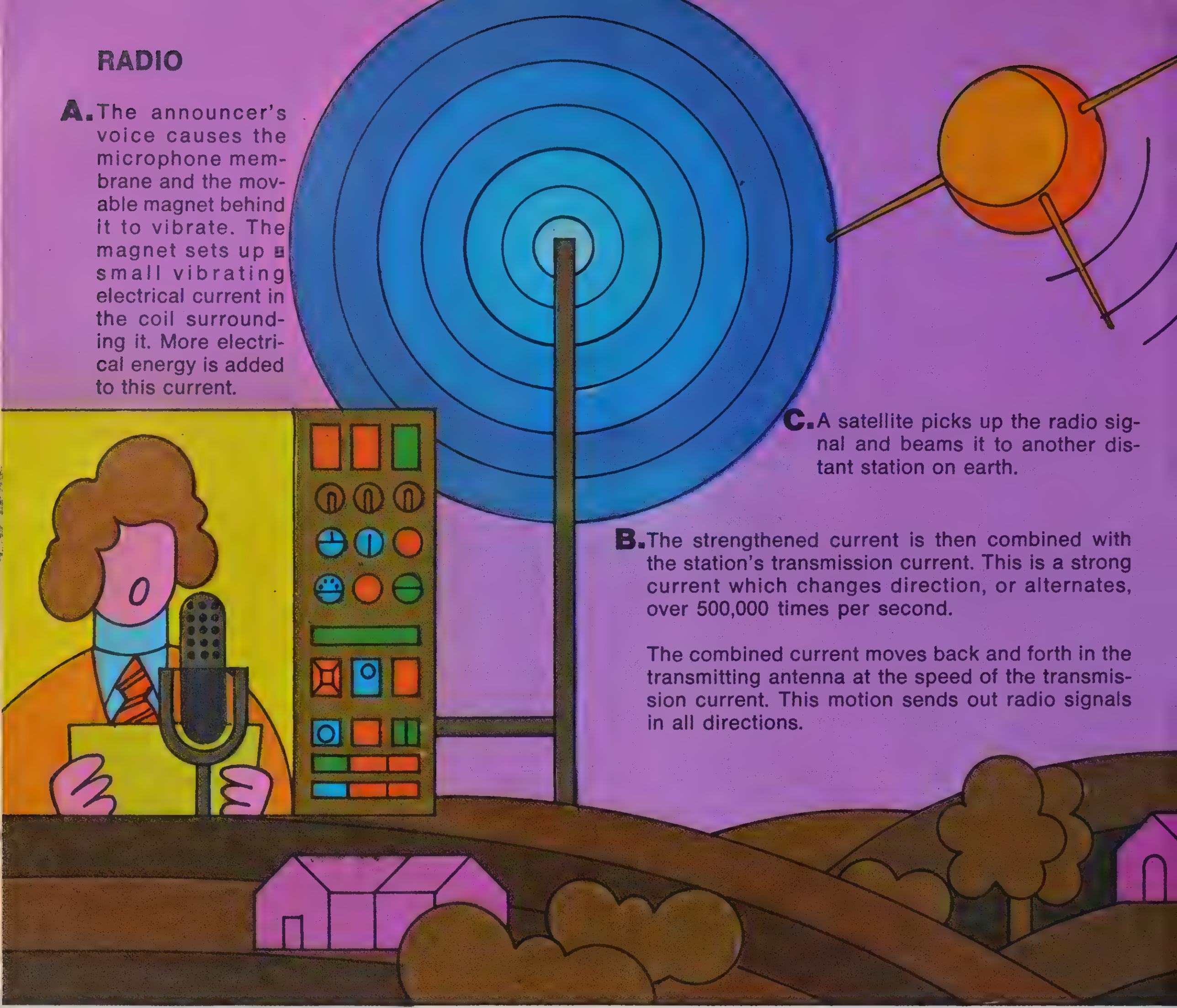
At the turn of the century a young Italian named Guglielmo (gü lyel′mô) Marconi (mär kō′nē) invented a more powerful electrical system than Hertz's. Marconi could send Morse code messages without wires. He connected a telegraph key into the sending part of his system. A sending operator used the electric contact key to open and close the circuit. When he closed the key, a spark jumped an air gap of about one millimeter between two metal balls. The radio signal was produced by the spark as it jumped the gap. And the radio operators at the receiving end heard intermittent long and short sounds over *earphones* (small diaphragms made to vibrate by electromagnets). It did not take long for this means of communication to be used widely over the Atlantic Ocean shipping lanes, and between the United States and Europe.

Voice and music without wires

Can you imagine the surprise of shipboard radio operators on Christmas Eve, 1906, when they heard music? Although they were not far out to sea, they had expected only code messages. But the radio operators were hearing music broadcast from Professor Reginald Fessenden's radio laboratory over 1.6 kilometers away.

Fessenden used a microphone to change sound vibrations into an electric current similar to that in the telephone. He then mixed this sound current with the radio transmission current. The receiving antennas changed the radio signals back into electrical current which was converted back into the original sounds in the earphones of the radio operators.

Until DeForest invented the vacuum triode in 1907, the human voice could be sent only a short distance. The signal became weaker as it moved away from the transmitter. A series of triodes was



RADIO

A. The announcer's voice causes the microphone membrane and the movable magnet behind it to vibrate. The magnet sets up a small vibrating electrical current in the coil surrounding it. More electrical energy is added to this current.

B. The strengthened current is then combined with the station's transmission current. This is a strong current which changes direction, or alternates, over 500,000 times per second.

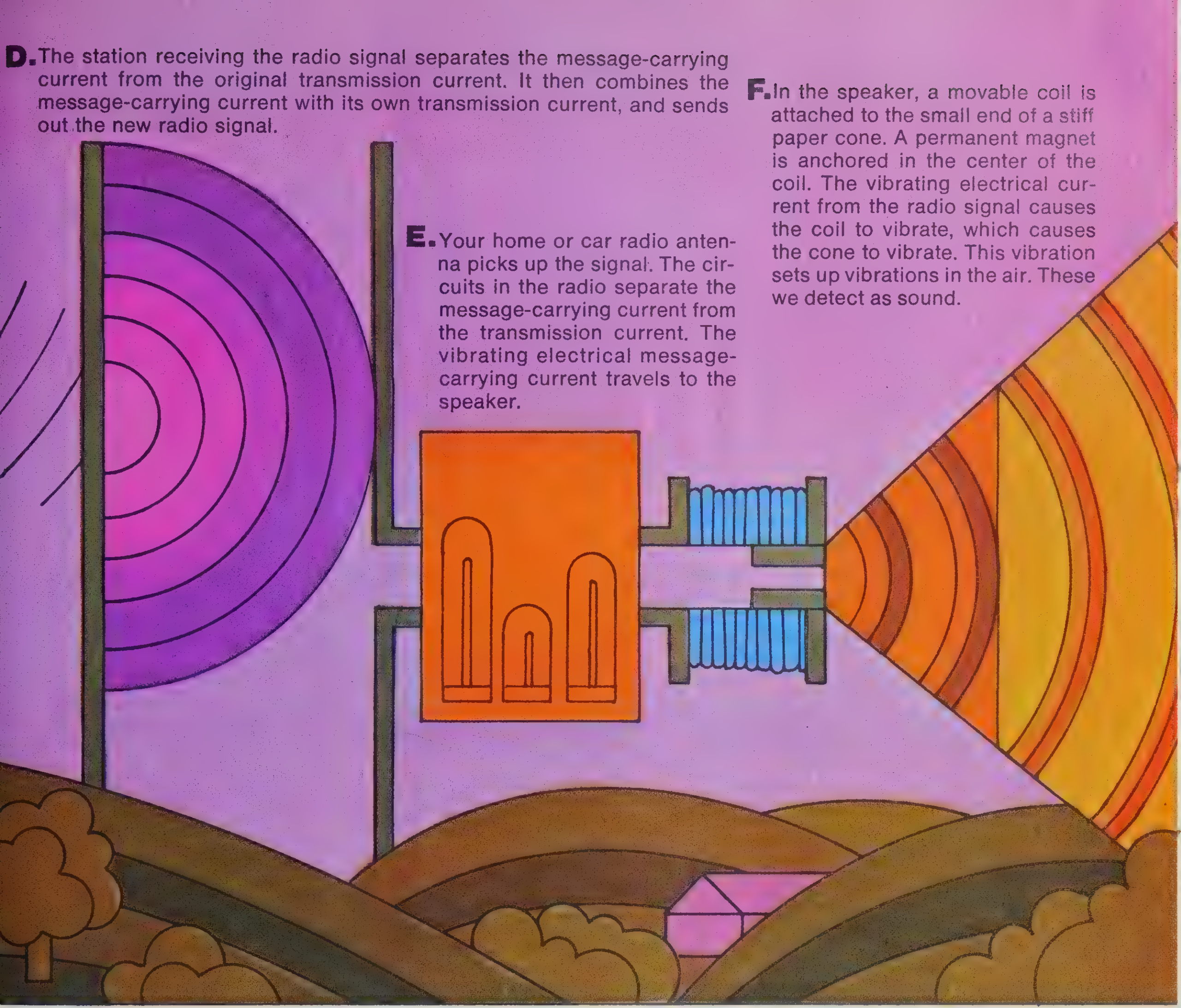
The combined current moves back and forth in the transmitting antenna at the speed of the transmission current. This motion sends out radio signals in all directions.

C. A satellite picks up the radio signal and beams it to another distant station on earth.

used to *amplify* (or strengthen) weak current from the antenna receiving the weak signal. In this way, very distant signals could be detected and understood. The invention of more complex vacuum tubes and of semiconductors has helped to advance worldwide radio communication.

Pictures through the air

Although it did not become commercially available until much later, television was really not far behind radio. V. K. Zworykin, an American physicist, patented the iconoscope, one of the first



D. The station receiving the radio signal separates the message-carrying current from the original transmission current. It then combines the message-carrying current with its own transmission current, and sends out the new radio signal.

E. Your home or car radio antenna picks up the signal. The circuits in the radio separate the message-carrying current from the transmission current. The vibrating electrical message-carrying current travels to the speaker.

F. In the speaker, a movable coil is attached to the small end of a stiff paper cone. A permanent magnet is anchored in the center of the coil. The vibrating electrical current from the radio signal causes the coil to vibrate, which causes the cone to vibrate. This vibration sets up vibrations in the air. These we detect as sound.

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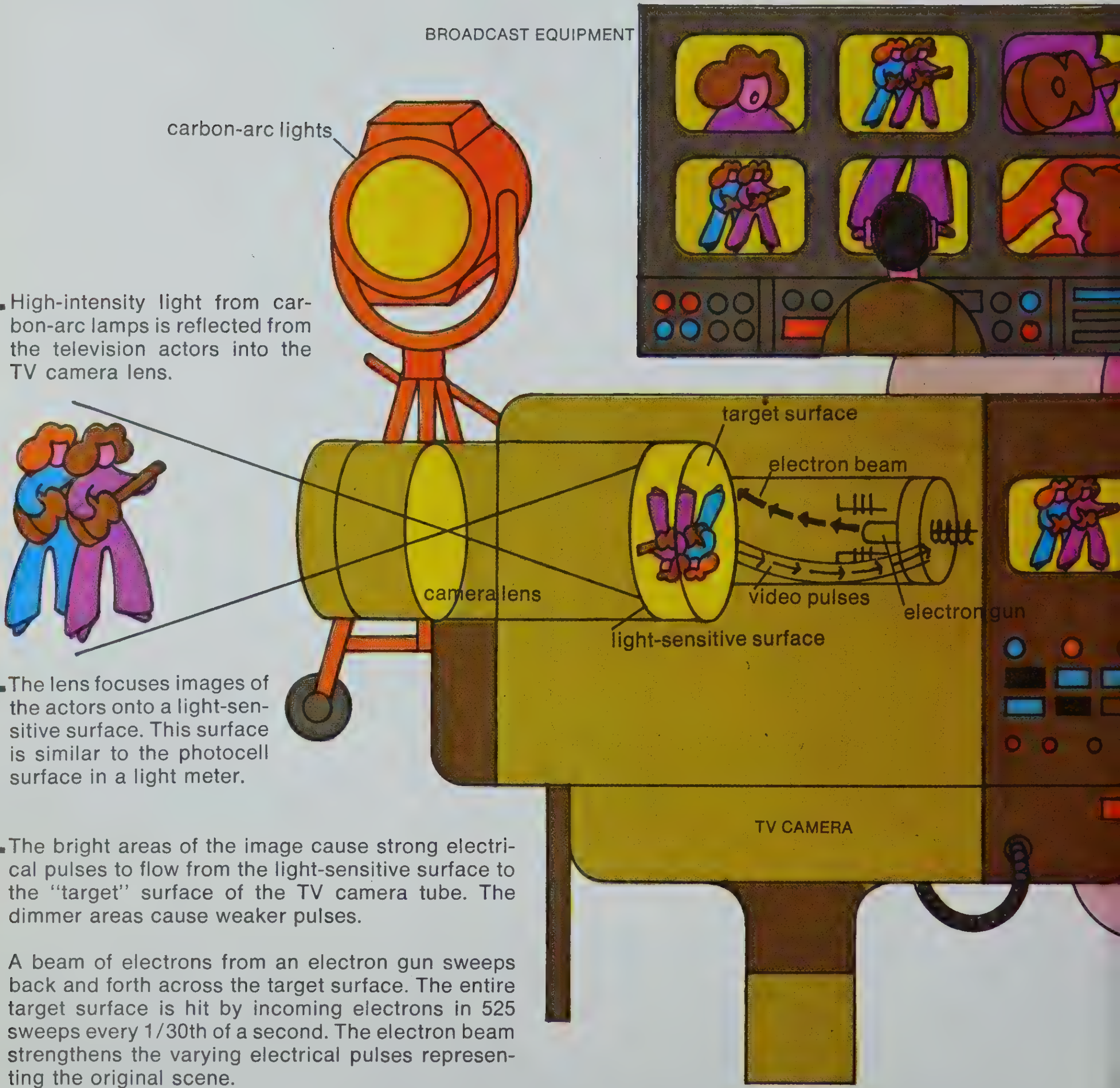
television camera tubes, in 1923. Later, both the National Broadcasting Company (NBC) and the Columbia Broadcasting System (CBS) operated experimental television stations in New York City in 1930 and 1931. Regular television service was introduced in 1939, although television as you know it did not exist until after World War II.

The vacuum tubes in your television set are diodes, triodes, and modified versions of these tubes. They change the signals that enter the TV set to currents that can be converted by the picture tube and the speakers into sounds and visual images.



A. High-intensity light from carbon-arc lamps is reflected from the television actors into the TV camera lens.

B. The lens focuses images of the actors onto a light-sensitive surface. This surface is similar to the photocell surface in a light meter.

C. The bright areas of the image cause strong electrical pulses to flow from the light-sensitive surface to the "target" surface of the TV camera tube. The dimmer areas cause weaker pulses.

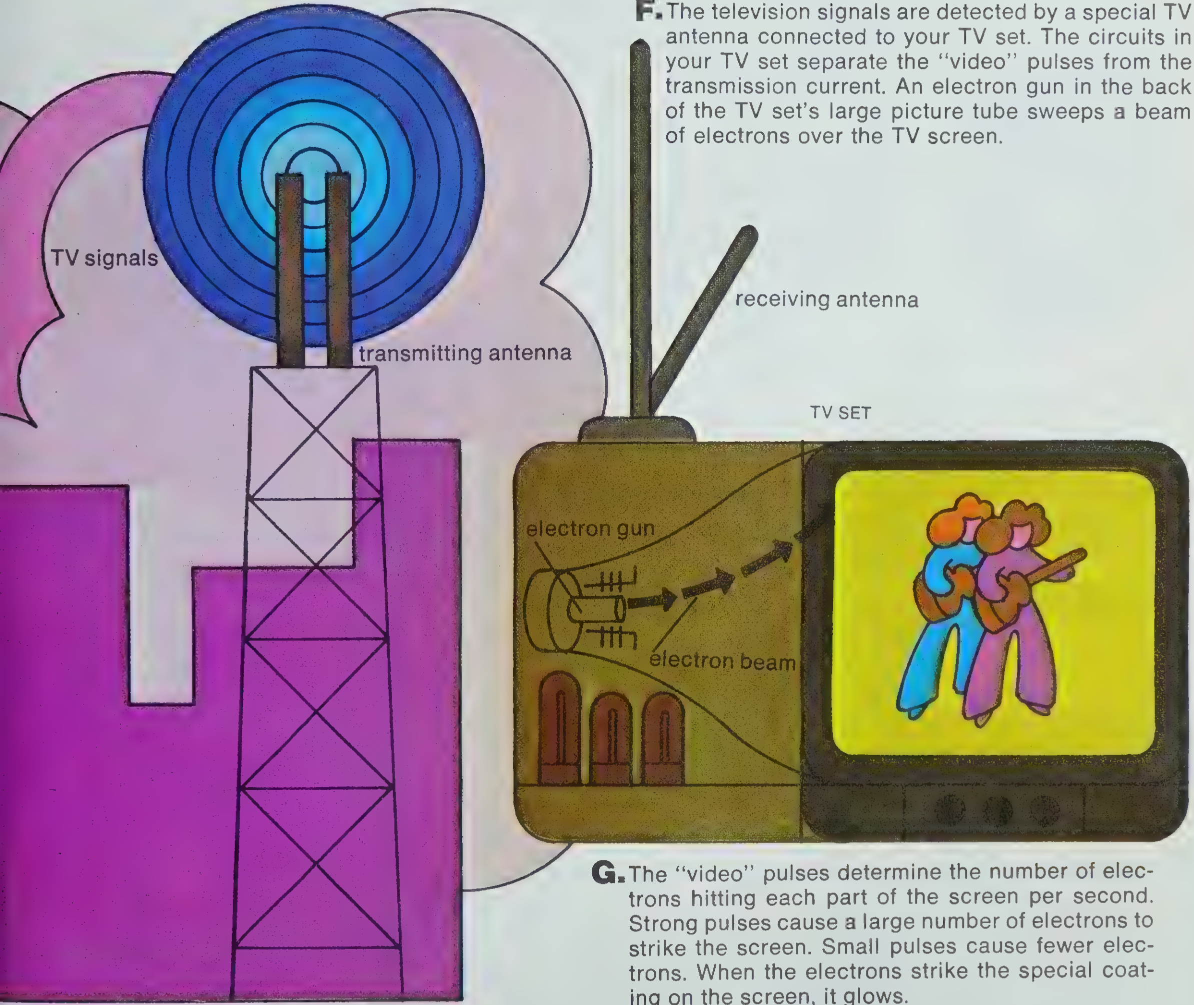
A beam of electrons from an electron gun sweeps back and forth across the target surface. The entire target surface is hit by incoming electrons in 525 sweeps every 1/30th of a second. The electron beam strengthens the varying electrical pulses representing the original scene.

The strengthened electrical pulses bounce off the target surface. They are turned into an electrical current, sometimes referred to as "video" pulses.

D. After the "video" pulses leave the TV camera, they are combined with the station's transmission current. This is a strong electrical current which moves back and forth over 100 million times a second, at a different speed for each TV station.

E. The combined current changes direction in the transmitting antenna at the speed of the transmission current. This alternating current causes television signals to be sent out in all directions.

F. The television signals are detected by a special TV antenna connected to your TV set. The circuits in your TV set separate the "video" pulses from the transmission current. An electron gun in the back of the TV set's large picture tube sweeps a beam of electrons over the TV screen.



G. The "video" pulses determine the number of electrons hitting each part of the screen per second. Strong pulses cause a large number of electrons to strike the screen. Small pulses cause fewer electrons. When the electrons strike the special coating on the screen, it glows.

The more electrons a certain spot receives, the more brightly it glows. The electron beam sweeps over the entire screen 30 times each second and our eyes see the same action picture transmitted by the TV camera.

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Chapter 8: The Whirring of Motors

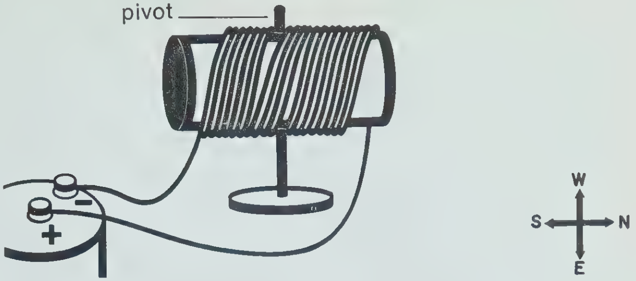
8

You come home after a busy day at school, raid the refrigerator, and put a record on the turntable. After kicking off your shoes and turning up the volume, you're ready to snack and listen to your favorite group.

Have you ever wondered what makes the turntable turn? Or, how about motion in other electrical appliances in your home? How does electricity cause motion in a washing machine, an electric fan, or an electric shaver?

Electromagnetism is used to change electrical energy to the energy of motion in these and countless other electrically operated devices.

Electromagnetism put to use



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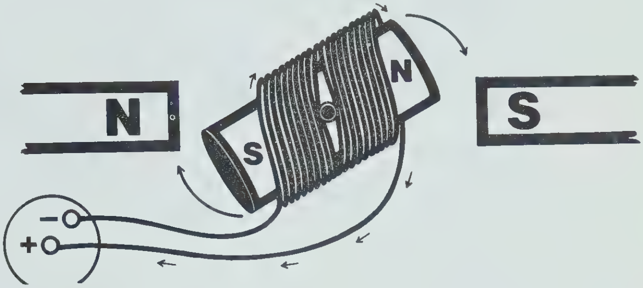
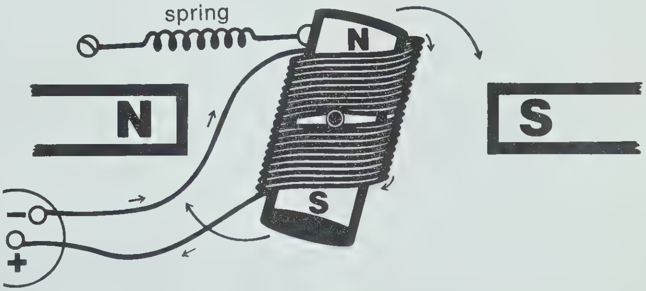


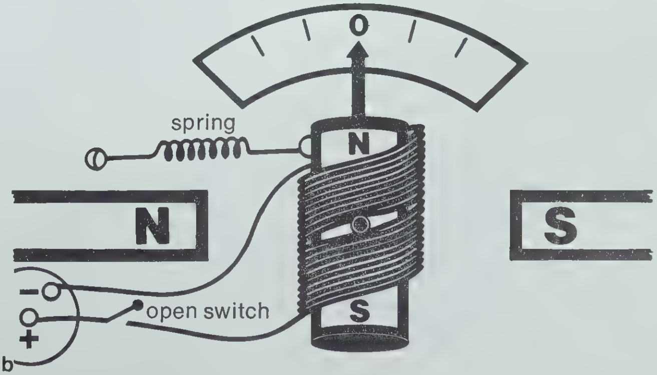
8·3

How can electromagnetism produce rotating motion? Assume that the electromagnet in figure 8·2 is placed on a pivot and allowed to rotate freely. You know that an electromagnet has a magnetic field similar to a bar magnet. Would this pivoting electromagnet act as a compass and line up with the earth's magnetic field?

What would happen if you placed it between two permanent magnetic poles (figure 8·3)? Suppose you attached a spring to the electromagnet as in figure 8·4a. Which way will the electromagnet turn? How might the spring affect the electromagnet's motion? If you increase the current through the electromagnet you will make the electromagnet stronger. In such a case, how will the spring holding the electromagnet be affected?



8·4a



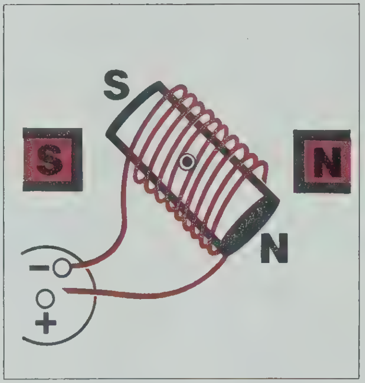
8·4b

If you attach a pointer to the electromagnet as in figure 8·4b, you will have a meter. Such a meter can be used to measure the current in a circuit. See if you can figure out how.

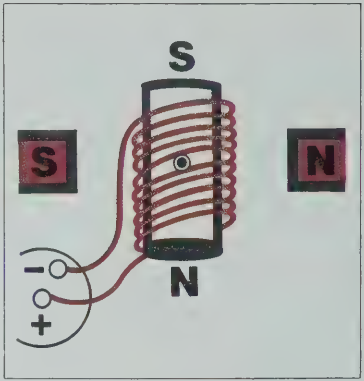
You have seen how an electromagnet mounted on a pivot between two permanent magnetic poles can be used as a meter. In figure 8·5 you can see what will happen if the spring holding the electromagnet in the meter is removed. You have here the main part of an electric motor. You'll find a fancier version of this kind of motor in every kind of home appliance that involves rotating motion: electric drills, phonographs, food blenders, and sewing machines.

You can make the electromagnet in figure 8·5 turn continuously in one direction by reversing the poles of the electromagnet each time it reaches the positions in figure 8·5c and 8·5g. One way you might reverse the poles of the revolving electromagnet is by reversing the direction of the current through the coil.

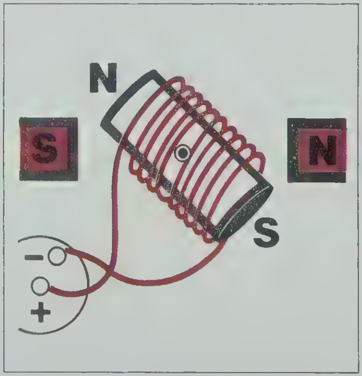
It is not very practical to reverse the battery connections to the coil every half turn of the revolving electromagnet. You could not move rapidly enough or give enough attention to moving the connections at exactly the right instant. Of course you might connect



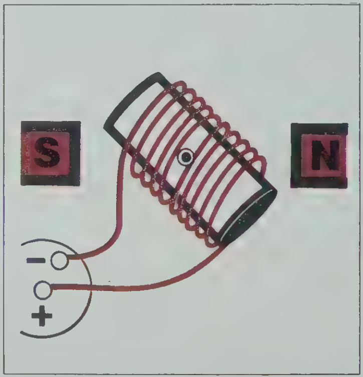
8·5a The electromagnet is between permanent magnetic poles. The like poles of the permanent magnets and the electromagnet are near each other. The circuit is open. In which direction would the above rotating electromagnet tend to turn when the circuit is closed?



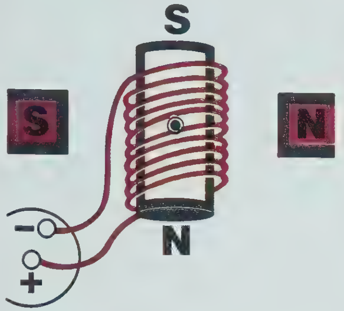
8·5b The electromagnet is now perpendicular to the permanent magnetic poles. In which direction will it tend to turn?



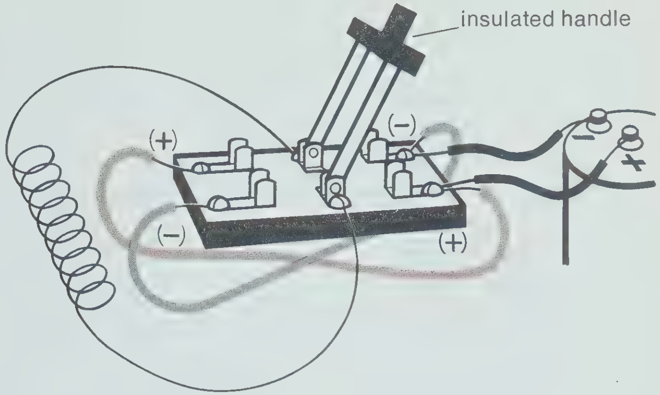
8·5c Because of its motion, the electromagnet may turn a little past the poles of the permanent magnets. Now which way will the electromagnet tend to turn?



8·5d Reversing the direction of the current in its coil will reverse the poles of an electromagnet. When the wires from the coil are untangled and reattached to the battery as above, which will be the N-pole of the electromagnet? Now which way will the electromagnet tend to turn?

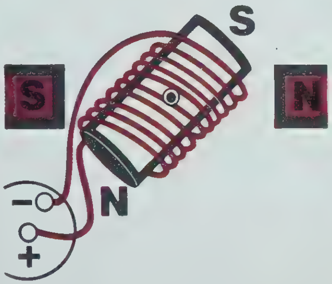


8·5e The electromagnet is now perpendicular to the permanent poles again. Note the direction of the current through the coil. In which direction would the rotor now tend to turn?

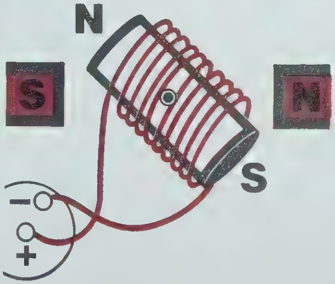


REVERSING SWITCH

8·6



8·5f Would the above electromagnet tend to continue turning in the same direction as it is now going?



8·5g The electromagnet has again turned a little past the poles of the permanent magnets. What would you have to do to make it keep turning in the same direction?

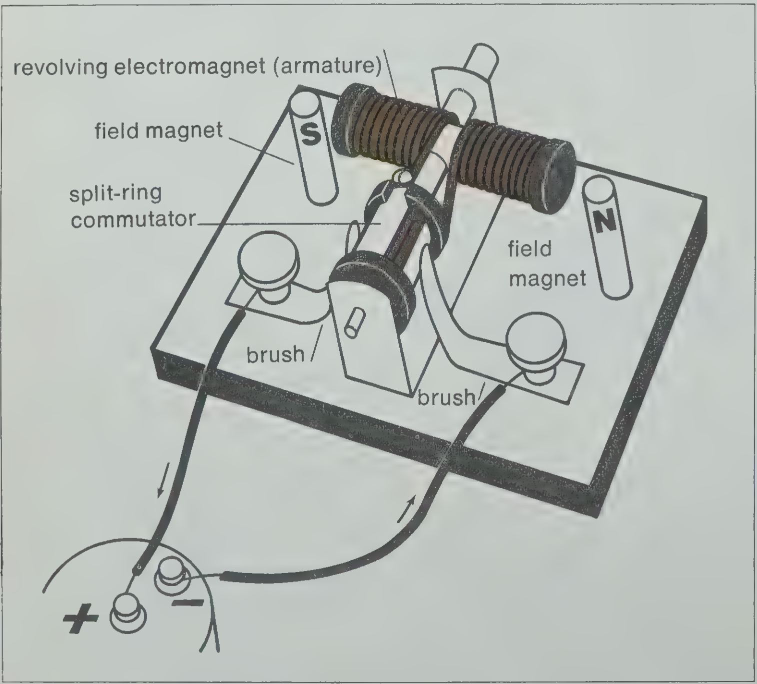
the ends of the coil to a reversing switch. Then you would have to move the switch only when the revolving electromagnet reached the right point in its rotation. But you might still have trouble moving rapidly enough.

You need a means of reversing the poles of the revolving electromagnet every half turn without twisting the connections from the battery to the coil. It would help to have a switch that rotated with the electromagnet so that the wires would not become twisted.

The invention of the *split-ring commutator* provided a switch that would turn on the same pivot as the revolving electromagnet. The split-ring commutator consists of two halves of a copper ring mounted on an axle so that they do not touch each other. The two halves of the ring are attached to the two ends of the wire coil (figure 8·7).

Pieces of a conductor are mounted to the frame, one on each side of the commutator. These pieces are called *brushes* because they remain in place and brush against the split-ring commutator as it rotates. Wires from the battery are attached to the brushes. In this way current is delivered to the rotating coil without the wires' becoming tangled.

With a complete circuit, current flows from the battery to a brush, to one half of the commutator in contact with that brush. It continues through the revolving electromagnet to the other half of the commutator, to the brush touching that half, and back to the battery. Thus, each half of the commutator is in contact with a different terminal of the electricity source every half turn. And the halves of the commutator are attached so that the current through the coil is reversed at the proper moment. The revolving electromagnet continues turning and you have an electric motor.



8·7 Notice that the armature rotates between opposite poles of two other magnets. These magnets are called *field magnets*.

Motor energy

When you turn on an electric motor, the current passes through the revolving electromagnet. This electromagnet is called the *armature*. If you connect an ammeter between the current source and the armature, you can measure the amps passing through the armature. In a similar way, a voltmeter connected with one wire on each side of the armature can tell you the volts used by the armature. And by simply multiplying volts times amps, you can find the electrical power of the motor in watts.

TEST YOURSELF

1. *Describe how an electromagnet is used to measure electric current.*
2. *Name the parts of a working electric motor and explain the function of each part.*

What if you had a horse?

The motor in figure 8·8 is using 12 volts. The ammeter shows a current of 1 amp passing through the circuit. How much energy per second (or power in watts) is the motor using?

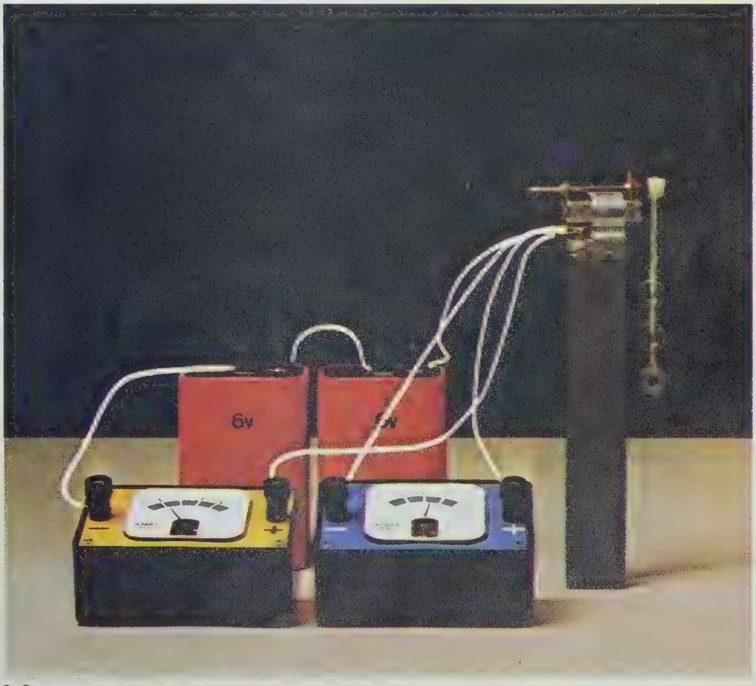
A motor large enough to lift a passenger elevator would use much more energy per second. An apartment-building elevator is connected to a 200-volt power source. It will lift a given weight to the sixth floor in two minutes with a 15-amp current. The motor will be using energy at a rate of 200 volts × 15 amps = 3000 watts.

Before the invention of the elevator, horses were used to lift objects by means of a rope and pulley. It might have taken four average-sized horses to lift the apartment-building elevator to the sixth floor in two minutes. The electric motor used to lift the elevator might be marked either 3000 watts or four horsepower. As with many other measurements from the past, the unit *horsepower* is still with us. So today, either watts or horsepower are used to show the rate at which a motor uses energy.

Household appliances run by electric motors use electrical energy at a variety of rates. In some variable-speed appliances, such as the electric blender or the electric drill, the rate at which energy is used depends on the speed at which the motor is run. Some common appliances and the rates at which they use energy are listed in Table 1.

Table 1

APPLIANCE	WATTS	HORSE-POWER
Coffee Pot	920	1.2
Drill	125–145	.17
Lawn Mower	750	1.0
Typewriter	60	.08
Waffle Iron	1150	1.5



8·8

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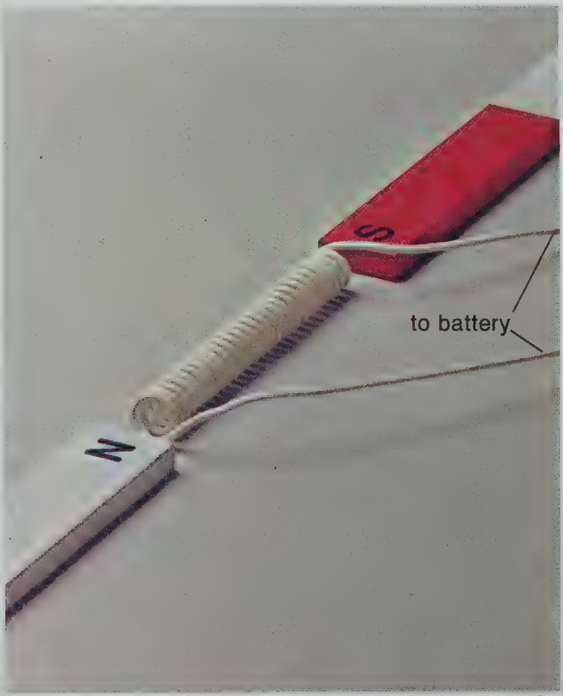
Batteries are not the only producers or *generators* of an electric current. Earlier, in Chapter 7, you learned that you could use a permanent magnet to generate an electric current in a coil of wire. At that time, you moved the magnet, and a current flowed through a stationary coil. But you can generate a current just as easily if you rotate a coil between two permanent magnetic poles.

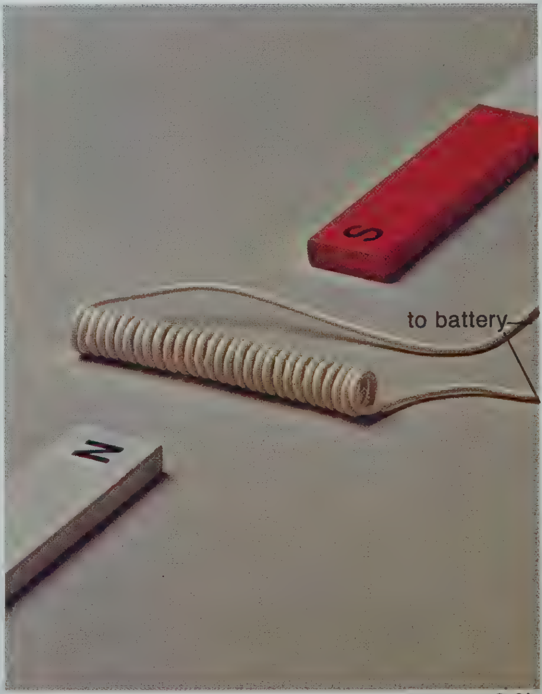
As you know, a motor has an electromagnet that rotates between two or more permanent magnets. But you could rotate the electromagnet by hand while the brushes are attached to an ammeter instead of a battery.

As the coil rotates in the magnetic field between two stationary permanent magnets, the field strength within the coil changes. The field within the coil is at maximum strength when the coil is in the position shown in figure 8·9a. The field within the coil is at minimum strength when the coil is in the position shown in figure 8·9b.

Thus the more rapidly the rotating coil is spun in the magnetic field, the more rapidly the magnetic field within the coil changes, and the greater is the amount of electricity generated. The motor becomes an *electric generator*



8·9a



8·9b

Table 2

	Energy per Charge	Charges per Second	Energy per Second
Tom	60 volts	0.2 amps	? watts
Susan	90 volts	0.3 amp	? watts
Jerry	30 volts	0.1 amps	? watts

and can supply electrical energy for other electricity users.

The faster you turn the electromagnet (armature) of the generator in figure 8·10, the brighter the bulb will burn. From this evidence, how do you think the speed of the armature is related to how much energy per second (watts) a generator will produce? Fifty volts are being supplied by the generator and 0.15 amps are being sent through the filament of the lamp. You can use these to calculate how much energy per second the generator is producing.

Now suppose your friends each take a turn at cranking the armature of the generator in figure 8·10. You can easily find out which student turns the crank the fastest. The ammeter and voltmeter readings for three students are given in table 2. How much energy per second did each student generate?

The current generated by the students is direct current. That is, it flows in one direction only. It can not be used by most American appliances, which are designed to use alternating current, the kind supplied by the outlets in your home or school. If you're interested in how this kind of electricity gets to your home and school, read "What's Behind that Electrical Outlet in the Wall?" on page 197. Then you might like to read some of the unusual history of the electric motor and generator in "Who Invented the Electric Motor?"

TEST YOURSELF

1. *Define the unit of measurement "horsepower."*
2. *Describe how to operate an electric motor so that it becomes an electric generator.*
3. *If you increase the speed of its armature, how will you change the amount of power put out by a generator?*

8·10

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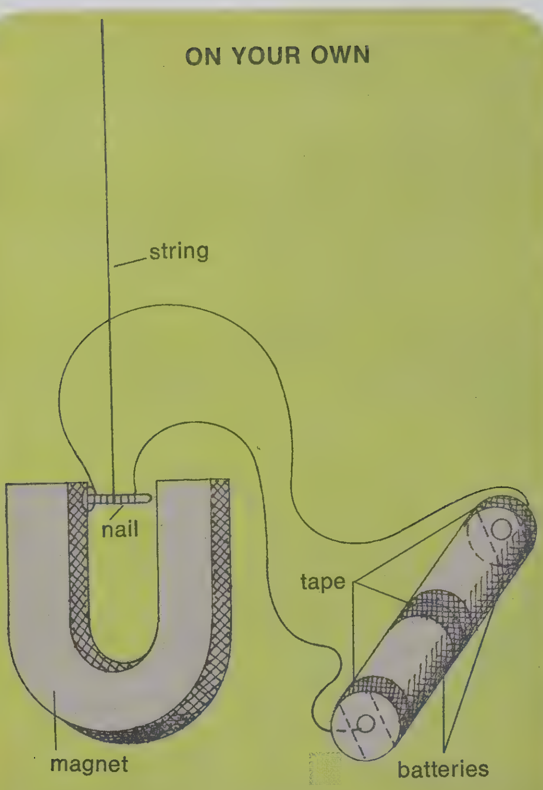
ON YOUR OWN



Motor-action demonstration

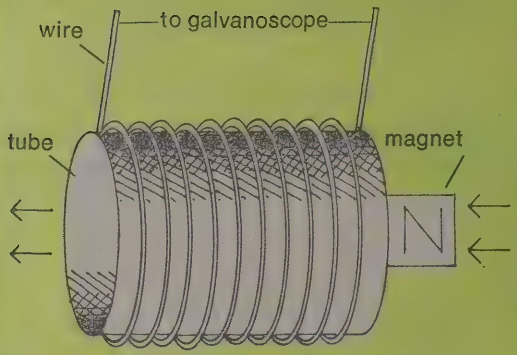
You can demonstrate simple motor action with these inexpensive materials:

1 horseshoe magnet
2 1 1/2-volt D batteries
1 5-meter (5 1/2-yd) length #24 insulated copper magnet wire
1 5-cm (2-in) iron nail
String

PROCEDURE: Wind at least 100 turns of wire around the nail, leaving a 25-cm (10-in) length of wire at each end. Tie a length of string around the center of the coil. Suspend the coil by the string so that it is hanging between the poles of a horseshoe magnet as in the illustration. Connect the two batteries in series.

The coil should be hanging so that it is free to turn. Now close the connections between the coil and the batteries, and observe. Reverse the connections to the batteries and observe again. You have demonstrated motor action.

ON YOUR OWN



Simple generator

You can generate a measurable current with these materials:

1 bar magnet
1 tube from a roll of wrapping paper or aluminum foil
Simple compass galvanoscope (page 165)
20 meters (22 yds) #20 insulated copper wire

PROCEDURE: Wind about 50 turns of wire tightly around the paper tube. You may have to tape it down to keep the wire from coming off. Connect the ends of the wire to the galvanoscope.

Move a bar magnet in and out of the tube. The needle on the galvanoscope will move when there is a current running through the wire. Notice when the needle moves. Vary the speed at which you move the magnet in and out of the coil and notice what happens to the needle. Let the magnet stay in the wire and note the needle movement.

If you have enough wire, wind about 100 turns around the tube and repeat the experiment. Notice what happens. Or, use a stronger magnet to repeat the experiment. Note the difference in the current produced as you change the strength of the magnet and the number of turns in the coil.

Alternating current from its source to the home

What's Behind that Electrical Outlet in the Wall?

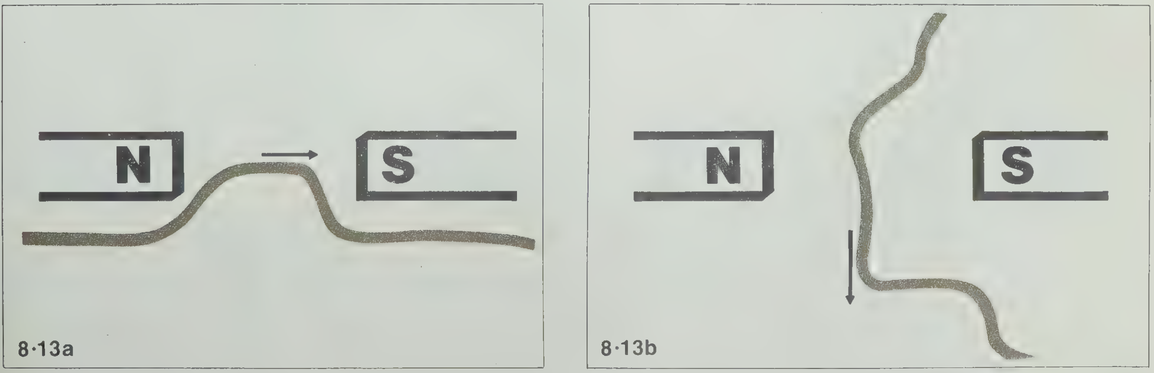
You don't need an electric-motor-changed-to-a-generator (page 194) to produce an electric current. You can produce an electric current by moving a permanent magnet in and out of a coil of wire. The direction of the current depends on which pole of the magnet you put into the coil and on whether the magnet is entering or leaving the coil. You can find the relationship between the magnetic pole, the direction of the motion, and the direction of the current flow in the coil. (See the activity on the previous page.)

An electromagnet and another coil

Instead of a permanent magnet, you can also use an electromagnet to generate an electric current in a coil. You can move a smaller-diameter electromagnet in and out of a larger-diameter coil. The current will again be generated in the larger coil. But remember that this larger coil must be part of a closed circuit, different from the closed circuit of the smaller coil. If you want to see how much current is being produced you can include a meter in the circuit of the larger coil. The current moves in one direction as the electromagnet enters the coil and in the opposite direction as it leaves.

To understand how a current can be produced in a coil of wire, let's take a look at how it can be produced in a straight wire which is part of a closed circuit. If you move the straight wire in a magnetic field, as in figure 8·13a, no electric current will flow in the wire. If you move the same straight wire in the same magnetic

8·13 The "straight" or uncoiled wire is being moved in the direction in which the arrow is pointing.



8·13a

8·13b

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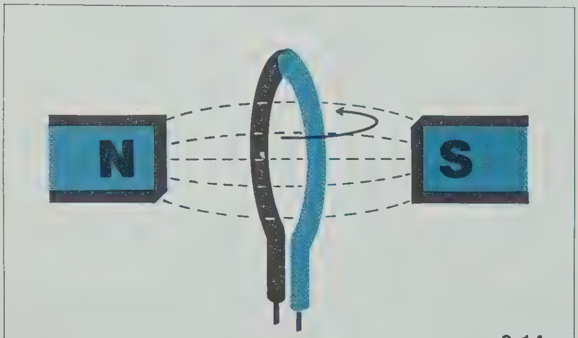
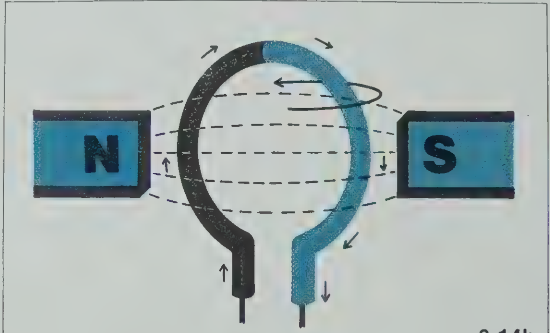
field, as in figure 8·13b, an electric current is made to flow in the wire in one direction. The current will be made to flow in the wire in the opposite direction if you move the straight wire through the magnetic field in the opposite direction.

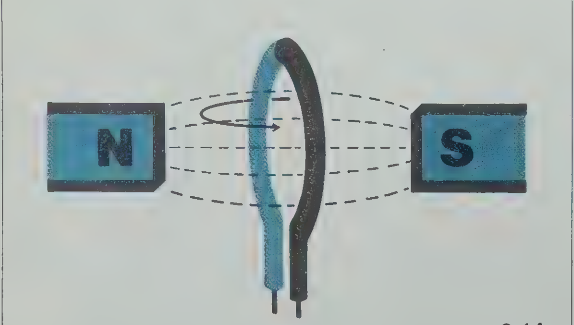
Now suppose you make a single loop from that straight wire which is part of a closed circuit. When you rotate the single loop of wire in a magnetic field, you will again produce a current in the loop. But no current will flow in the wire when the parts of the loop are moving in the magnetic field as in figure 8·14a. When the parts of the rotating wire loop are moving as in figure 8·14b, a current is made to flow around the entire loop in one direction. Rotating the



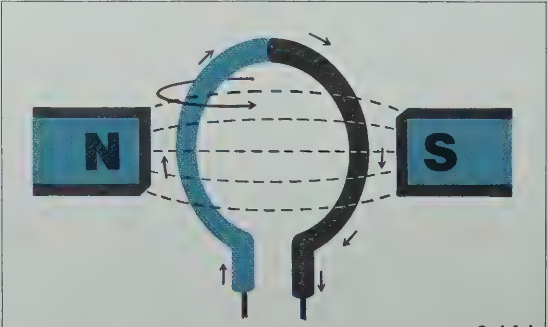
8·14a



8·14b



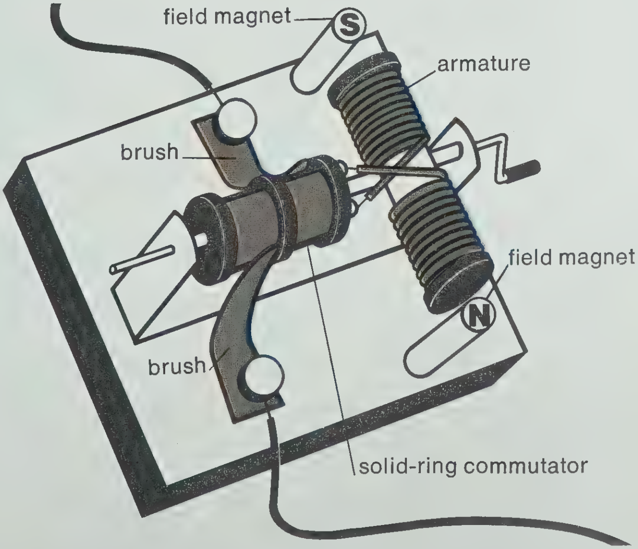
8·14c



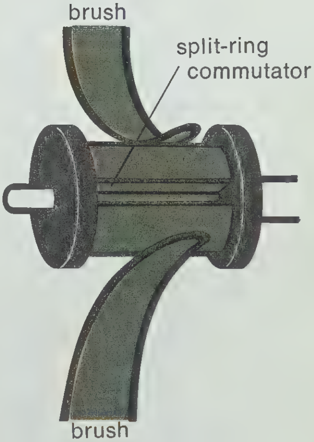
8·14d

loop one-half rotation to where its parts are again moving across the magnetic field will produce a current in the opposite direction (figure 8·14d).

To increase the amount of electricity generated, you can wrap an insulated wire many times around a soft iron rod. As you rotate this coil between the opposite poles of a permanent magnet or two other electromagnets you are using the basic parts of an alternating-current generator. The alternating-current generator in figure 8·15a is similar in design to the massive generators used to provide electric power for our homes, schools, and industry. Notice that it does not have a split-ring commutator as did the motor-changed-to-generator that you studied earlier. So, in a way, it is more simple than a direct-current generator.



8·15a



8·15b

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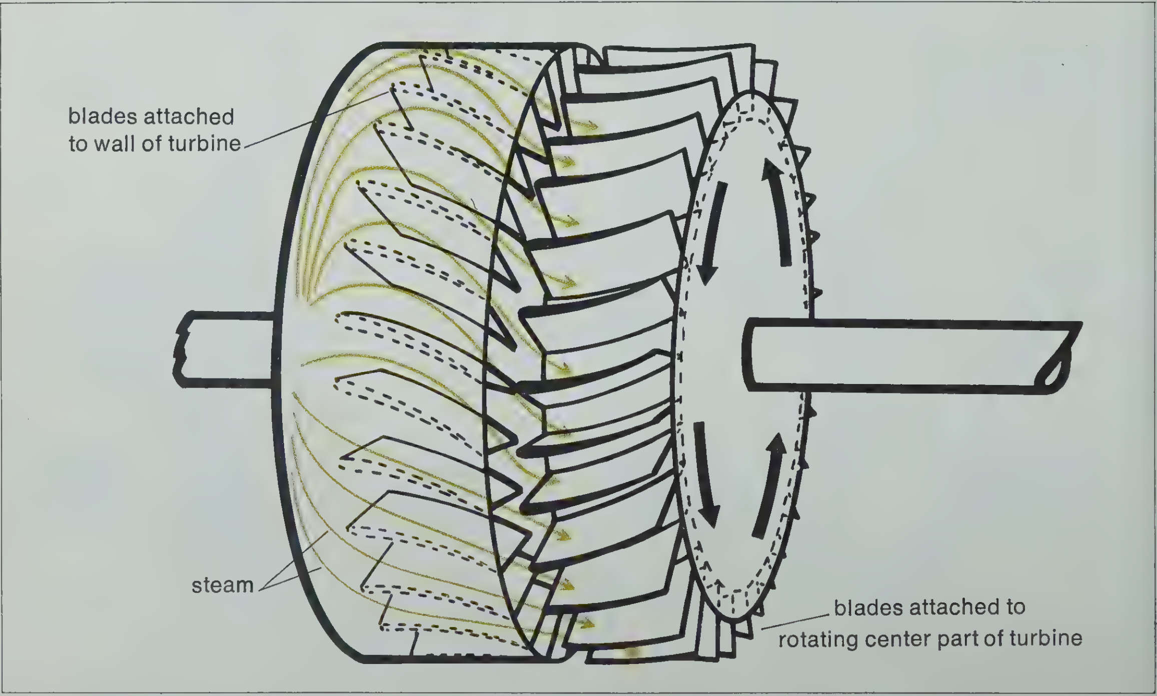
Power plants

As you probably remember, the electrical energy per second supplied by power sources is measured in watts. One thousand watts is called a *kilowatt.* Tens of millions of kilowatts are supplied by power plants around the world. There are three main kinds of power plants presently in use.

One type of power plant burns coal to produce electrical energy. The coal is burned to produce superheated steam. The steam, under pressure, turns large *turbines* connected to alternating-current generators.

Falling water is also used to produce electrical energy. Many large dams throughout the world generate electricity by sending water through the turbines as it passes from the top of the dam to the river below.

8·16 Steam is directed by the stationary blades of the turbine so that it pushes against the rotating blades, causing them to turn.


blades attached to wall of turbine
steam
blades attached to rotating center part of turbine

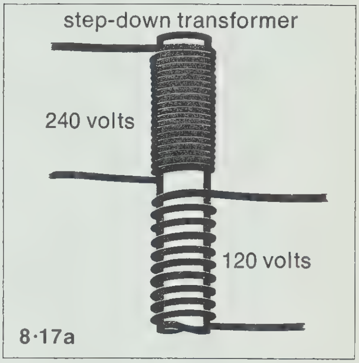
A growing number of nuclear power plants are also being built to produce electricity. The extreme heat of the nuclear reactions in the core of the reactor is used to change water into superheated steam. As in the power plants which use coal, this superheated steam drives large turbines connected to alternating-current generators. All steam turbine plants require a large supply of cooling water to condense the used steam. Nuclear plants need even more cooling water than coal-burning or gas-burning power plants because additional water is needed to cool the nuclear reactor.

From the power plant to you

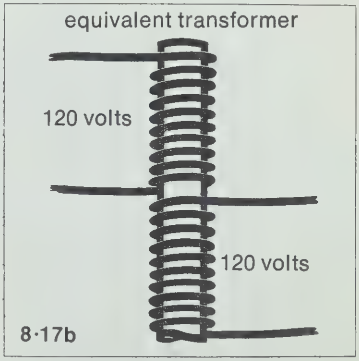
Except for the coal-burning ones, most power plants are usually far from the communities which they serve. So the electrical power (kilowatts) produced must be sent through wires to where it is needed. The generators in these power plants produce electrical energy in the form of high-amperage, low-voltage electricity. This situation creates a problem because the more amps that move down a wire over a long distance, the more electrical energy is lost as heat energy along the way. There is a solution to this problem. The same amount of electrical power can be efficiently transported over the long-distance wires if the electrical energy is changed in form. The amperage can be decreased as the voltage is increased. This change is made with a device called a *transformer.*

Two wire coils, each part of a different closed circuit, are the basic parts of a transformer. The alternating current from the generators is connected to one of the coils. Around this first coil, the current sets up a magnetic field which keeps increasing and decreasing as the current alternates. The second coil is inside or alongside the first one. The changing magnetic field in the first coil produces a changing, or alternating, current in the second coil (figure 8·17) just as it would if you moved the first coil in and out of the second coil.

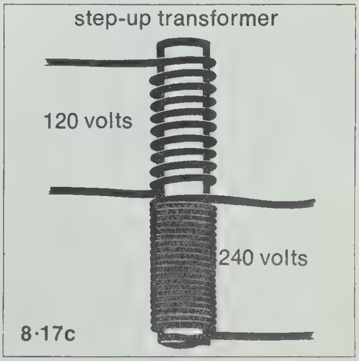
The voltage produced in the second coil will be the same as that in the first coil if the number of loops in both coils is the same. If there are fewer loops in the first coil than in the second coil, the voltage will be higher in the second coil. And the voltage will



8·17a



8·17b



8·17c

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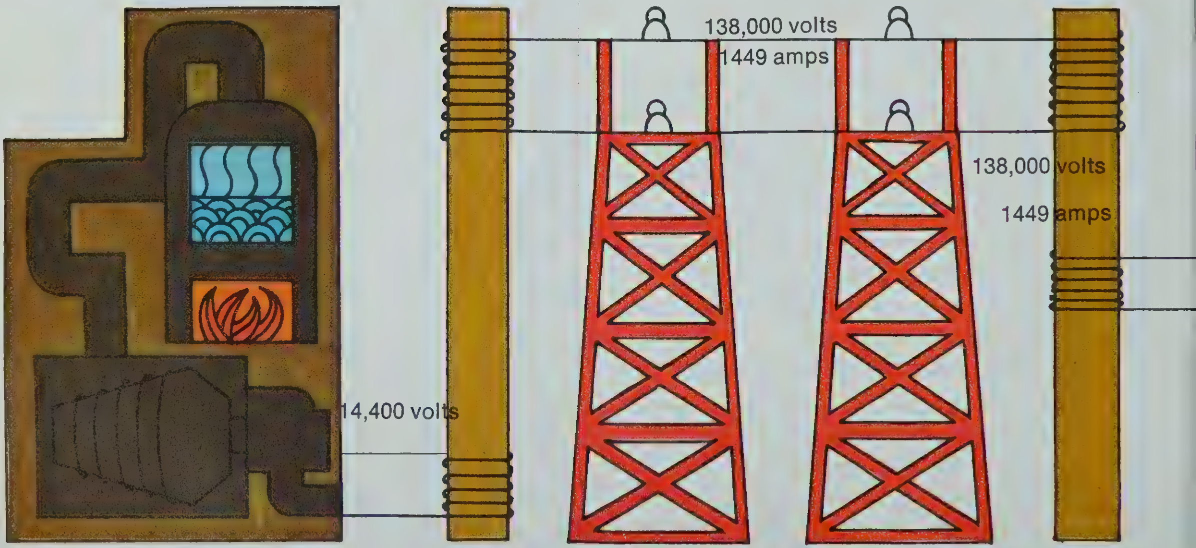
be lower in the second coil if the first coil has more loops than the second coil.

Very little power is lost as the electric energy travels from the first coil to the second coil. When the voltage increases from one coil to the other, the amperage must decrease since the total wattage remains the same. Or when the voltage decreases from one coil to the other, the amperage must increase.

Electrical power at a power plant is sent through "step-up" transformers. These produce higher voltage and lower amperage in the second coil. Electrical power transmitted at high voltage and low amperage loses little of its energy during long-distance



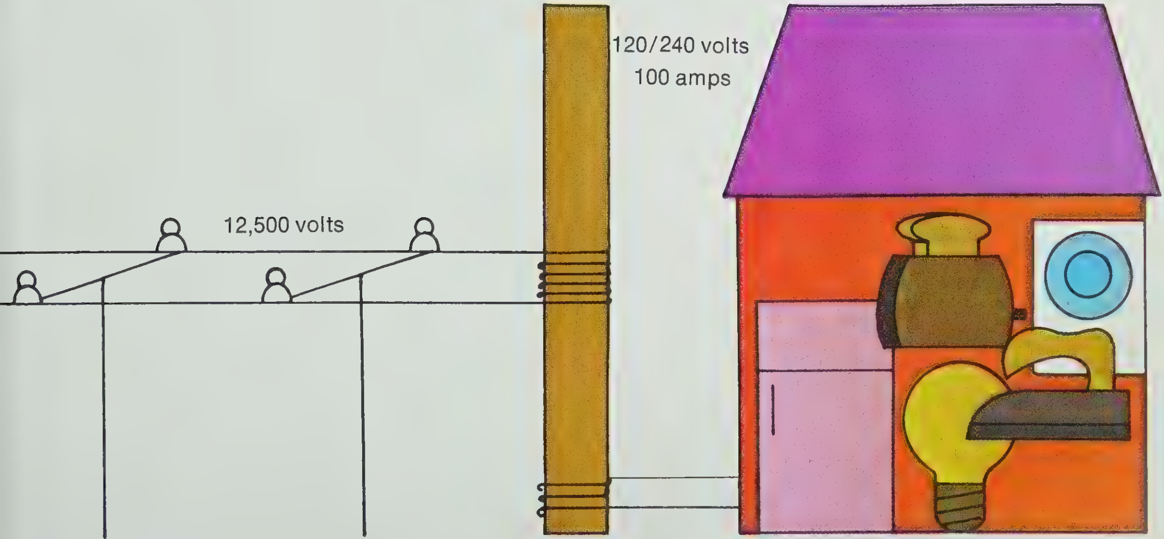
If a power plant produces 200,000 kilowatts of electrical power at 14,400 volts, then the current is approximately 13,900 amps.

The step-up transformer raises the voltage for transmission across the country.

Voltages sent across the country on high-voltage and low-amperage transmission lines usually vary from 138,000 to 345,000 volts. Extra high voltage lines carry 765,000 volts and connect large power systems with each other.

High-voltage and low-amperage transmission lines bring the electrical power with little loss to the step-down transformer substation near your city or town.

transmission over wires. But high voltage current is very dangerous and it is not as useful in household circuits. So the electricity is sent through some "step-down" transformers before it enters homes and offices. A group of these transformers is arranged so that each of them takes only part of the energy from the high-voltage transmission wire. They produce a lower voltage and a higher amperage in the second coils.



The substation lowers the voltage to the 12,500 volts carried by the overhead lines or underground cables in your neighborhood. The neighborhood line carries less power because the power carried by the transmission lines is split into many parts at the transformer substation.

A second step-down transformer near your home provides electrical power to operate your electricity users. It steps down the 12,500-volt line to the 120-volt and 240-volt lines that enter your home. The power company recommends that these lines entering your home should carry a 100-amp current.

LIBRARY

The invention and development of the electric generator and motor

Who Gets the Credit?

Volta invented the battery and Bell invented the telephone. But who gets the credit for inventing the handy device known as the electric motor? That's a simple enough question. But there is no simple answer to it. The electric motor was not invented by any one person. Instead, it was invented, invented, and invented again—until finally scientists in many places realized it had been invented, and started to use it.

It's interesting that so many people invented the electric motor before people finally began to use it. To get a better idea of why this happened, we need to take a look at the history of electricity during the 1800's.

As you may remember, Ampère demonstrated in 1820 that an electric current can generate magnetism. He also suggested that a magnet might be able to generate electricity. Many scientists worked on that idea in Europe and the United States. Within a few years, two scientists each invented the motor—for the first of many times.

8·19 Faraday's laboratory

The very beginnings: Faraday and Henry

Michael Faraday was born to poor Scottish parents in Surrey, England, in 1791. He was apprenticed to a bookbinder when he was twelve. There he came across many books on scientific experiments. Faraday also went to hear lectures at the nearby Royal Institution, a famous institution for scientific research. By the time his apprenticeship was finished, he knew that he wanted more than anything to work with the scientists at the Royal Institution. He obtained work there as a laboratory helper, the lowliest of jobs.

Before too long, Sir Humphrey Davy, a scientist at the Institution, recognized Faraday's interest in science. Faraday was promoted to Davy's assistant because he showed Davy a notebook that he had made on Davy's lectures. The young man was always filling up his notebook with new observations, and with ideas for new experiments, especially on electricity.

In 1820, Faraday heard of Ampère's experiments on electromagnetism. He wrote a short memo in his notebook: "Convert magnetism into electricity."

8·20 Faraday in his laboratory

It was a tall order even for a gifted scientist like Faraday. The very next year, though, Faraday achieved a result that seems very important to us now. He showed that when a movable wire made contact with an electrical circuit, in the presence of a magnet, it generated a force that pushed it away from the magnet. Faraday hinged his wire in such a way that it moved in a circular path around the magnet. He used electromagnetic forces to produce a circular motion. Faraday had invented an electric motor!

Well, not quite. Faraday wasn't very interested in motion at the time. He was interested in that brief electric current that was produced (page 170) by the magnet. He wanted to "convert magnetism into electricity." He left his "motor" and went to other projects.

It wasn't until 1831, after five series of unsuccessful experiments, that Faraday finally succeeded in his goal of generating electricity from magnetism. He mounted a copper disk between the poles of a strong magnet. When he turned a crank to rotate the disk, an electric current was generated in wires connected to the disk.

This first generator didn't generate a very strong current. But unlike the voltaic pile, which consumed expensive zinc plates, it didn't use up anything except a little elbow grease. Physicists began to use generators for their research. A British firm started manufacturing small laboratory generators as early as 1834.

Meanwhile, across the Atlantic, another scientist was working on some of the same ideas as Faraday. Joseph Henry, who was also

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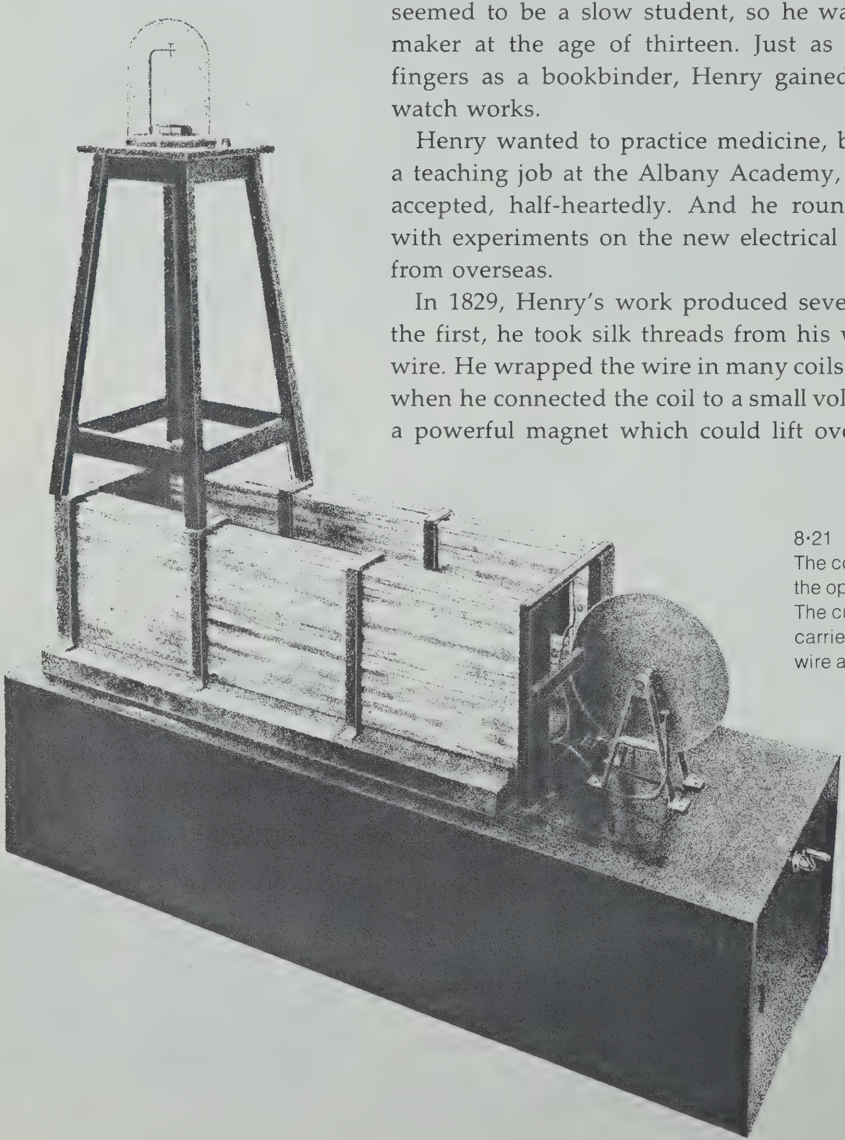
of Scottish ancestry, was born in Albany, New York, in 1797. He seemed to be a slow student, so he was apprenticed to a watchmaker at the age of thirteen. Just as Faraday developed clever fingers as a bookbinder, Henry gained skill and patience at the watch works.

Henry wanted to practice medicine, but in 1826 he was offered a teaching job at the Albany Academy, where he had studied. He accepted, half-heartedly. And he rounded out his teaching life with experiments on the new electrical ideas that he heard about from overseas.

In 1829, Henry's work produced several important devices. For the first, he took silk threads from his wife's petticoat to insulate wire. He wrapped the wire in many coils around an iron core. Then, when he connected the coil to a small voltaic pile the device became a powerful magnet which could lift over a ton of metal! Henry's



8·21 Faraday copper-disk generator. The copper disk was turned between the opposite poles of two bar magnets. The current generated on the disk was carried to the carbon arc light by the wire at the right center of the disk.

design was basically the same as that of electromagnets used in modern generators and motors.

His next invention was an even greater achievement. Using one of his insulated wire coils and a magnet, he built a device that—like Faraday's invention—generated electricity. And, like Faraday, Henry also designed a primitive motor. But Joseph Henry didn't publish his experiments until after Faraday had demonstrated his achievements. The two scientists developed the same ideas, an ocean apart, without knowing of each other's work.

Faraday and Henry also shared a dedication to science. Faraday spent much of his time doing research for industry. His work brought money and prestige to the Royal Institution. With this money, the Institution could hire young scientists, just as they had hired young Faraday.

In the United States, Joseph Henry became the first secretary of the Smithsonian Institution, founded in 1846 as an institution for the increase and spread of knowledge. While serving as secretary, he fostered many large programs of research.

Both Faraday and Henry continued to publish research during the succeeding decades. But the drama of electricity was shifting away from the laboratory of the pure scientist, into the hands of the engineer.

8·22 Henry's electromagnet

The generator comes of age—1832 – 1873

In 1832, Hippolyte Pixii (pēk sē′), a Frenchman, made a generator that was more practical than those of Faraday and Henry. It used a revolving magnet and fixed coils. In 1833 another improved generator was developed by an Englishman named Saxton. This one had fixed magnets and revolving coils, which is the arrangement more frequently used today.

Both of these designs were for laboratory generators, to provide electricity for experiments. The fact is, there wasn't really much else for electricity to do. Lighting was done by gas or kerosene lamps. Heavy work was done by steam engine or muscle power.

The first real call for a better generator came from a very specialized place—the lighthouse. Lighthouses at the time were using a

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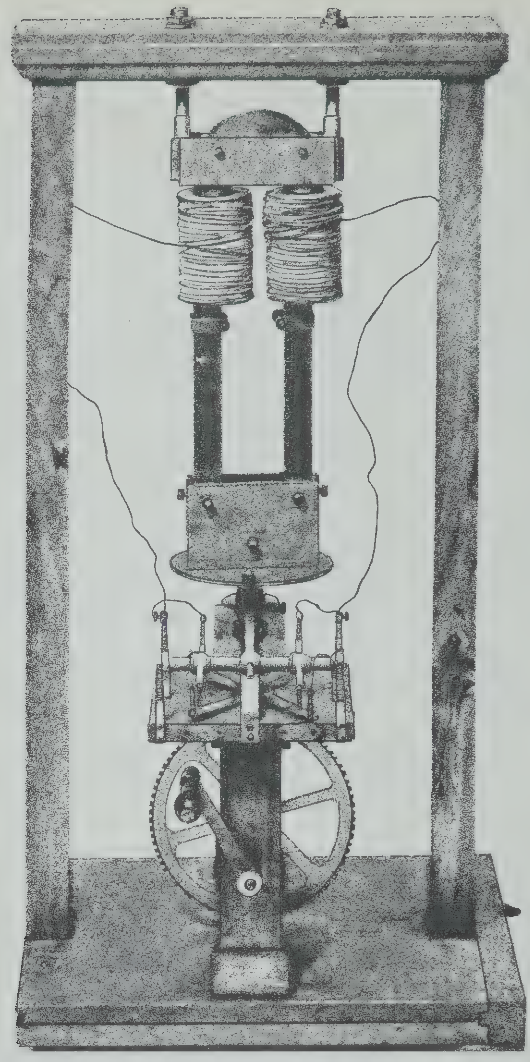

8·23 Pixii generator

relatively new type of light, called limelight, which required hydrogen and oxygen gases.

In 1850, a Belgian named Florise (flō′rēs) Nollet (nô le′) began taking patents for a generator to break apart water into hydrogen and oxygen gases for lighthouses. Nollet died in the midst of this work, in 1853. An Englishman, Frederick Holmes, continued his work.

For various economic reasons, the lighthouse project failed. But Holmes, who was something of an electrical wizard, had another lighthouse idea. He wanted to generate electricity, not for limelight, but for a carbon arc light.

He sought out Michael Faraday, who encouraged him to develop the idea. In 1857, Holmes built his first lighthouse. A steam engine rotated the generator's coils at 660 revolutions per minute, generating 1½ kilowatts of power. It made the high-resistance arc glow bright white.

The generator really came of age, though, in 1873. In that year, electric light produced by a generator designed by Zénobe Théophile (zā′ nôb tā′ ō fēl) Gramme (gram), a Belgian, won a competition over gaslight. It was installed to light a clock tower in Westminster, England. The machine that Joseph Henry had once called a "philosophical toy" had become a practical source of light-giving power.

Discovery: a generator is a motor is a generator. . .

Now people had a source of electrical power. Now they had a means to run motors, if any motors had been around to run. But all anybody had was a lot of big generators.

But wait. . .

In a generator, something (either coils or magnets) is rotated, and electricity is produced. So if electricity were *supplied*—wouldn't rotation be produced? If we really want to honor the inventor of the electric motor, we just have to find the one who first used electricity to rotate a generator.

But at this point, history disappears in a cloud of uncertainty. All that we know for sure is this: In 1873, Zénobe Gramme and an associate named Fontaine displayed two Gramme generators at the Vienna exposition. Someone—Gramme, Fontaine, or maybe a careless maintenance man—hooked up one generator to the coils of the other. The second generator, fed from the wrong end, started working backwards, turning electricity into a powerful mechanical rotation. The generator had become a motor.

But can we really say Fontaine, or Gramme, or a janitor invented the motor? Didn't Faraday invent the motor? Didn't Joseph Henry? Didn't countless scientists and engineers probably hook up their generators backwards at one time or another?

The reason that none of these inventors came forth to claim fame and fortune is that none of them could take the most important

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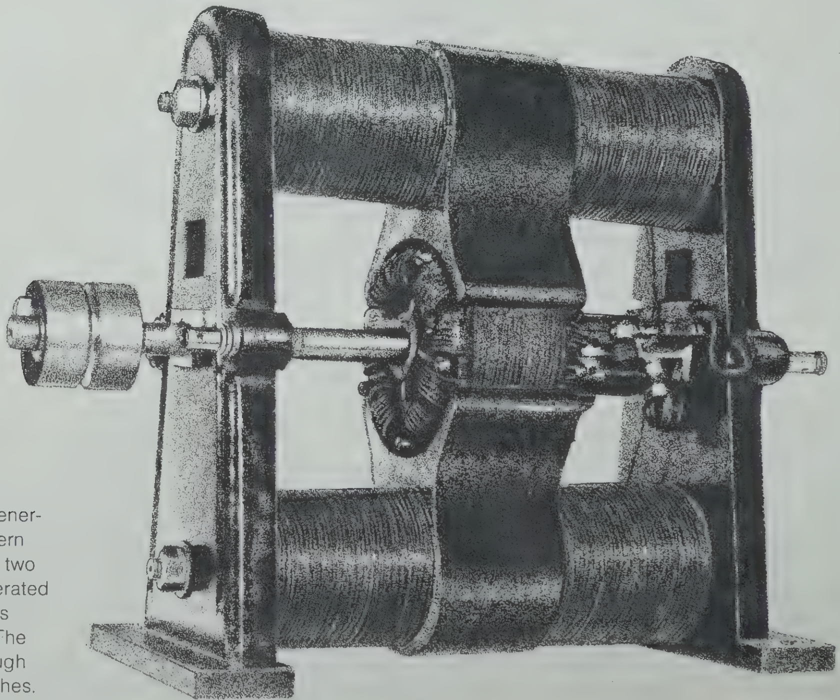
step in inventing the motor. None of them could *use* it. Taking that step required the last big electrical development of the 1800's—the production of cheap electrical power.

The first power stations and the AC/DC controversy

The Gramme generator was a direct current generator. ("Direct current" is often shortened to "DC.") That is, the current it supplied was a continuous stream, all in the same direction. By 1874, Gramme generators were being used in French and Russian ships. They supplied rotation for the propellers and electricity for lights.

Other generators in use at that time supplied alternating current. ("Alternating current" is often shortened to "AC.") The coils, as they rotated, generated current in pulses, first in one direction,



8·24 Gramme generator. This generator has the same parts as a modern generator. The coil turns between two electromagnets. The current generated in the coil is carried to the brushes on the right side of the armature. The current leaves the generator through the terminals attached to the brushes.

then in the opposite direction. There were many "cycles" or changes in direction, each second.

Thomas Edison, an American, favored direct current. His phonograph, electric light, and other inventions could be run more simply with direct current. In 1878, he designed a whole electrical system, using DC power. In 1882, he opened the Pearl Street electric power station, supplying direct current to New York City.

George Westinghouse, another American, was champion of alternating current. But Edison already had well-designed DC motors, and no one had come up with an AC motor.

Now the time was surely ripe for the electric motor to be invented again. In 1888, Nikola Tesla (tes′lə), a brilliant engineer working for Westinghouse, patented his design for an AC motor.

Within the next year or so, greatly improved AC motors were developed in Zurich and Berlin. The latest inventors of the motor really meant business. Their designs went into production almost as soon as they were finished. Countless uses for the motor had been found—vacuum cleaners, washing machines, and others. As soon as the public decided on AC or DC, the electronic age could get under way.

The most dramatic competition between AC and DC began when the United States government decided to build a huge power plant at Niagara Falls. Edison and Westinghouse both turned all their energies toward winning the contract. The contest became fierce, and sometimes unethical.

In 1893 the dust finally settled and Westinghouse emerged the winner. High-voltage transmission was seen to be an essential requirement for modern power distribution. Edison's DC designs could not reduce power losses at high voltage, so they were out of the running in the United States.

Once AC plants brought electricity into homes all over the U.S., the Tesla motor became the marvel of the day. Some people at the time said that Tesla had invented the electric motor. But you know that there was much, much more to it than that.

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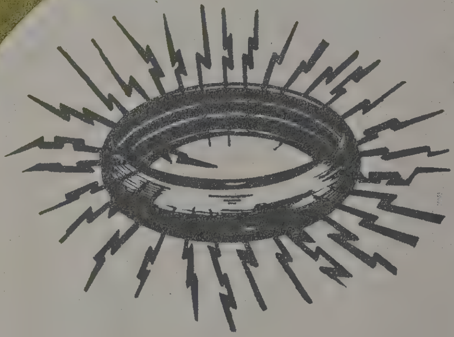


Electric Ring for Rheumatism.

These are the first rings introduced into the United States, all others being imitations. Their popularity has caused many rings to be placed on sale that are without any curative properties.

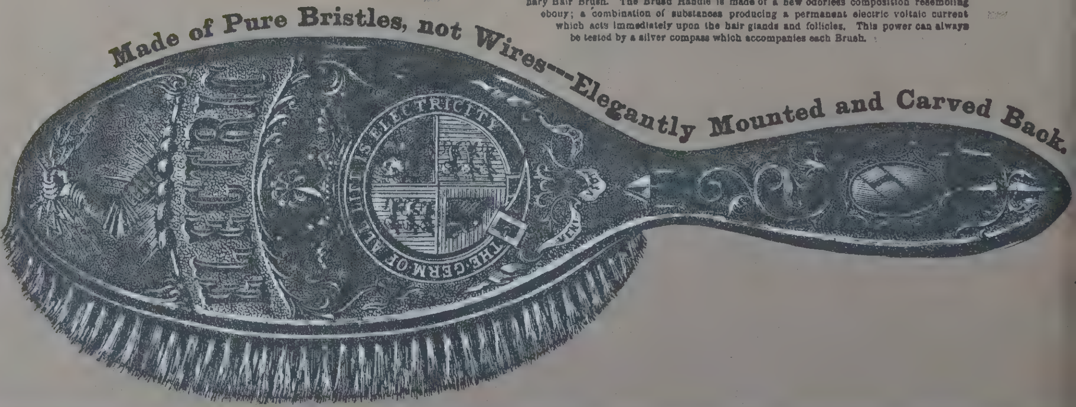
No. D2226 Gray metal polished, price, each.................................**85c**

No. D2228 Gray metal gold plated, on outside, price, each...............**$1.25**

DR. SCOTT'S ELECTRIC HAIR BRUSH.

A REMARKABLE INVENTION,

Which has won its way to royal favor in England, been cordially endorsed by the **Prince and Princess of Wales**, and written upon by the **Rt. Hon. W. E. Gladstone**, is now brought to the notice of the American public. It cures by natural means, will always do good, never harm, and is a remedy lasting for many years. It should be used daily in place of the ordinary Hair Brush. The Brush Handle is made of a new odorless composition resembling ebony; a combination of substances producing a permanent electric voltaic current which acts immediately upon the hair glands and follicles. This power can always be tested by a silver compass which accompanies each Brush.


Made of Pure Bristles, not Wires---Elegantly Mounted and Carved Back.
ELECTRIC
THE GERM OF ALL LIFE IS ELECTRICITY

-MYTHS

ELECTRICATING LINIMENT.

A NEW AND GREAT DISCOVERY.

NOTHING BEFORE HAS BEEN KNOWN LIKE IT. By a newly discovered process this liniment is electrically charged by a powerful current of electricity, whereby the ingredients undergo a powerful change which, when applied to the most severe cases of Rheumatism, Sprains and Bruises, effects immediate relief. It never fails in its Magical Effect.

Certain cure for Rheumatism, Cuts, Sprains, Wounds, Old Sores, Corns, Galls, Bruises, Growing Pains, Contracted Muscles, Lame Back, Stiff Joints, Frosted Feet, Chilblains, Etc. Persons suffering from partial paralysis of arms and legs will be rendered great benefit by its use, frequently regaining complete use of these members, also an application to the **Throat and Chest and externally for Lung Troubles; great relief will be experienced by rubbing the chest with this, the most penetrating liniment in the world. TRY IT.**

No. D1550. Price, bottles, 29c; per doz. $3.00

When electricity was first becoming a household term, many people made wild claims about its ability to cure anything from baldness to rheumatism to lung troubles. The advertisements on this page are only a few of the many examples of 1890's advertising featuring such items as "electric" hair brushes, tooth brushes, amulets, rings, corsets, back braces, and linaments.

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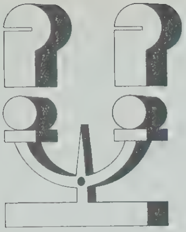

A thought and discussion question

Power Controversy

The time of the all-electric home, school, office, and factory is here. We heat and we cool with electricity. We use electricity to mow the lawn and to vacuum the rug. We keep our food in electric refrigerators and freezers. And we often prepare it on electric ranges. But where are we going to get power to supply our ever increasing need?

We are running out of ordinary sources of electric power. There are few rivers to dam. And we are trying not to build dams that would damage the balance of nature. The world has a limited supply of coal and oil. And burning these fuels pollutes our air. Coal-burning generator stations emit hundreds of tons of poisonous chemicals each day. They also emit carbon dioxide. And the carbon dioxide concentration in the atmosphere is rising about 2 percent every 10 years. Is electricity worth running eyes, smoggy skies, or building a dam that would flood the Grand Canyon?

Nuclear power may solve our problem. It is cheaper than coal or oil. Nuclear power plants presently cost more to build, but they cost a great deal less to run. Nuclear fuel does not have to be constantly transported to the power plant. One fourth of the plant's fuel is replaced yearly. And the fuel that is removed can be reprocessed and used again. In addition, nuclear plants produce medically useful radioactive chemicals as by-products. And they don't throw poisonous chemicals into the air we breathe.

But nuclear power plants may seriously upset the balance of nature. Imagine what could happen if a large amount of radioactive materials was released by accident. Those who favor nuclear power say that commercial nuclear power stations in the United States had completed 100 reactor years of accident-free operation by 1970. Those against nuclear power are not so optimistic. But there is no way to prove that the risk has been reduced to a tolerable level. Besides which, nuclear power plants do release a small amount of radioactivity into the air and ground waters when they are working well. Scientists are still debating the harm which that radioactivity might cause.

And then there is thermal pollution, the addition of heat to a river or lake which thereby raises its water temperature above normal.

All steam-turbine power plants cause some thermal pollution. But a one-million kilowatt nuclear power plant can empty 700,000 gallons of water per minute into a lake or river at 6–12°C (10–20°F) above the normal water temperature. A nuclear power plant produces 60 percent *more* waste heat than that produced by a coal- or oil-burning plant. Which brings us to another difference of scientific opinion.

Some scientists and most nuclear power engineers insist that returning heated water to a lake or river is harmless. Many ecologists and conservationists disagree. They feel that exposure to sudden temperature change may kill eggs and larvae of water animals. And they offer many other arguments: Rise in water temperature increases the amount of oxygen used by fish and other water organisms as it lowers the available oxygen in the water. It does so in two ways: It makes oxygen less soluble in water. And it speeds up use of oxygen by bacteria in the water. It also increases the chance for some fish to be affected by diseases and poisonous substances.

Conservationists and some weather experts also suggest that release of warm water might seriously affect nearby land areas. They say that evaporation of warmer water can contribute to fog along the coasts. And they say that the warm water can warm the air in the area where it is released. Then they ask how that might affect incoming weather fronts, outgoing weather fronts, and local rainfall.

Which brings us back to the original problem. Where are we going to get all that electric power? Should we cut down our standard of living and our power needs? Or should we wait until someone has proven whether nuclear power plants are safe enough, and that thermal pollution is or is not harmful? And if we wait, what should we do about the serious power shortage that now exists in the northeastern United States, and that threatens to become a problem for the entire nation? What do you think?

If you would like to read more about this subject look up the following topics in *The Readers' Guide to Periodical Literature*, in your library card catalog, or in an encyclopedia:

Air pollution

Ecology

Electricity, supply

Energy, supply and demand

Fossil fuels (coal and oil)

Nuclear power

Pollution

Thermal pollution

Unit 3: Motion

Walking is motion; talking is motion; running is motion; writing is motion. Lifting your arm to touch your nose is motion. Turning your head to look out the window is motion. Breathing is motion—being alive is motion.

Chemical signals within your body make your muscles contract and relax so that you *can* walk, talk, run, write, and touch your nose or turn your head. By your own motion, you can put other things in motion. You can push, pull, lift, and carry things. But you're only one source of motion.

Electric motors whirr. Car engines purr. Spacecraft blast off. Balloons float up. Leaves float down. The sources of motion are infinite.

From infancy, you start noticing how things move, what causes their motion, and what stops it. Explaining such observations is a different problem. This unit is about some very basic ideas concerning motion. These ideas, or principles, can be applied in any situation in which motion is involved.

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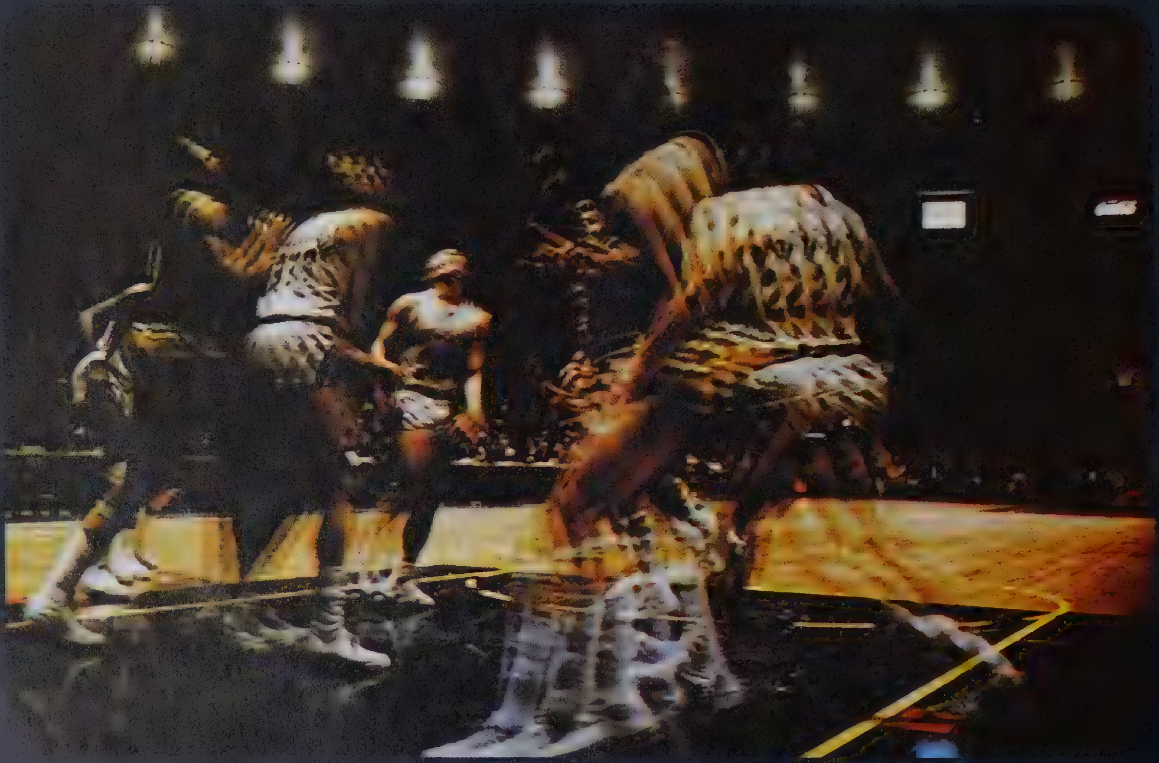

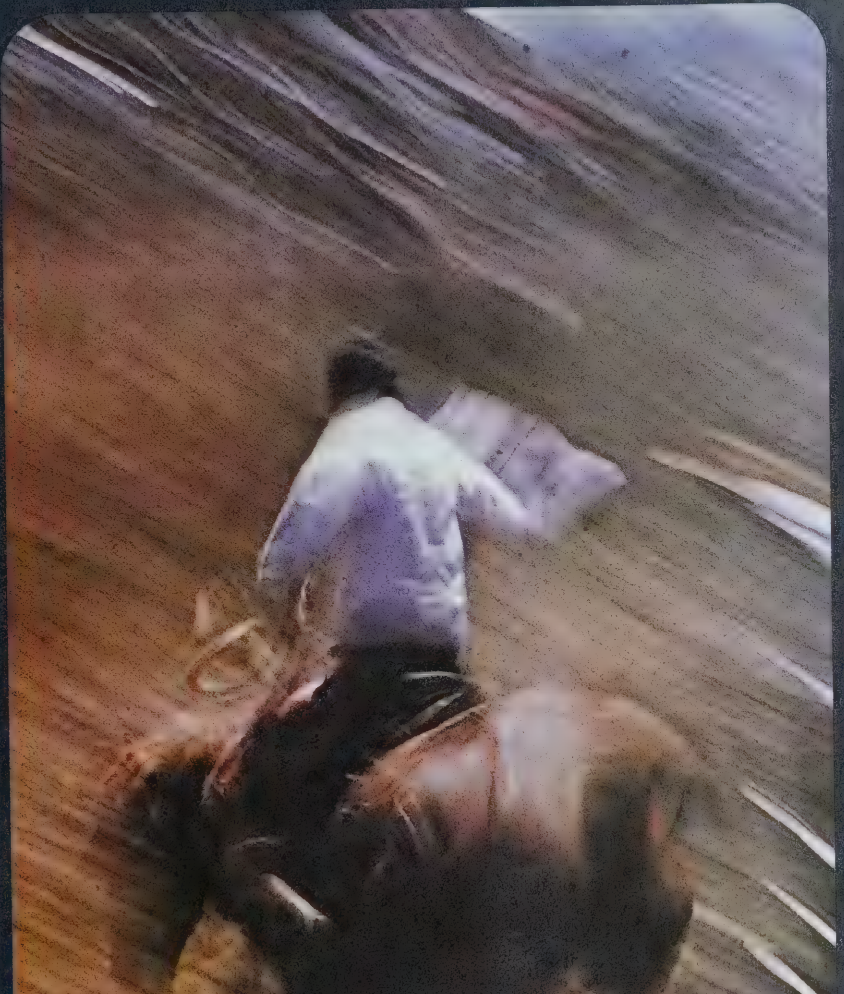

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Chapter 9: Things in Motion

9

Our subject is motion. Pick a moving object, any moving object. Say, a baseball in mid-throw. Now, consider the properties of that baseball—all the things about it that make it the moving object that it is.

You may think first of the baseball's size, shape, or surface texture. But concentrate on the *motion* of the baseball. What properties play a part in the baseball's motion?

In a way, many things about the baseball could affect its motion. But if you wanted to get down to basics, there are only a few things that stand out as general properties of the baseball's (or any moving object's) motion. You might call them (1) the way it starts, (2) the way it goes, and (3) the way it stops. These are the topics of this chapter.

Whoosh and thud

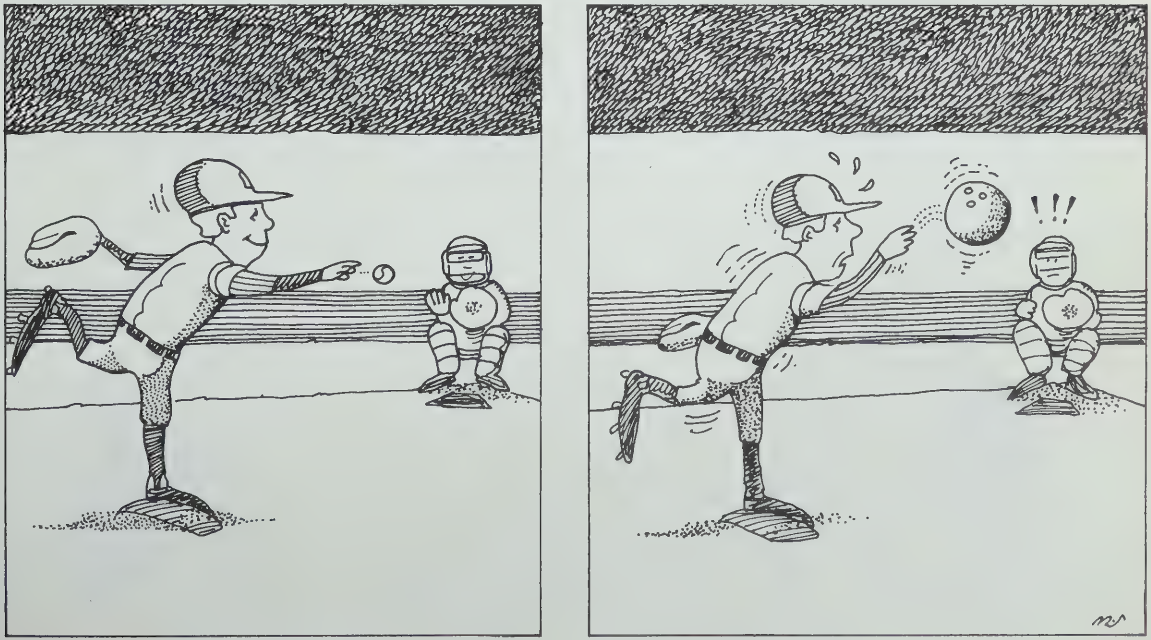
The first property of something in motion concerns how hard it is to get it started from rest. In the case of the baseball, that's the pitcher's problem. The last property concerns how hard it is to stop the object—the catcher's problem.

Do you think a ball that takes less effort to throw will also take less effort to stop? As an example, consider pitching and catching a baseball as compared with pitching and catching a bowling ball.

The effort needed to start an object moving is so closely related to the effort needed to stop it that you can think of them as one property. If you would like a name for the property that determines how easy it is to start or to stop the moving object, you might name this property after the sound the object makes as it is stopped.

In the case of the baseball, call this property the "thud" the baseball makes as it hits the catcher's mitt. The loudness of the thud can give you an idea of how hard the ball was to stop.

The other property, the way the ball goes, also produces a sound. You may have heard the sound of a ball going by your face. You could call it the "whoosh" of a moving object. The "whoosh" gives you an idea of how fast a ball is moving. That is, it gives you an idea about its *speed.*



9·1

Speed is the distance an object has moved divided by the time it took the object to move that distance. A baseball moves about 18 meters (m) from the pitcher's hand to the catcher's mitt. Suppose someone clocks the time it takes for the ball to reach the catcher's mitt. It might turn out to be 0.6 seconds (sec).

You can figure out the speed of the ball as follows:

$$\frac{\text{distance traveled}}{\text{time interval}} = \frac{18\text{ m}}{0.6\text{ sec}}$$

$$= 30\text{ m/sec}$$

However, this result might not be too accurate. The position of the pitcher's arm and that of the catcher's mitt can vary by half a meter or more.

Furthermore, a baseball travels so quickly that, even with an accurate stopwatch, the person doing the timing might be off a few tenths of a second in starting and stopping the watch. So let's take another example.

Imagine that you have just won a contest. The prize is a bus tour of Mexico. You are riding along a highway in Mexico, where, of course, distances are measured in the metric system. As you speed along, a clock says 3:30 just as you are passing a sign that says, "Ascención—260 kilómetros" (260 kilometers).

Later you see another sign, "Ascención—160 kilómetros." This time you notice it's exactly 4:30. So when the man behind you leans over the back of your seat and asks, "How fast have we been going?" you can figure it out in the following way:

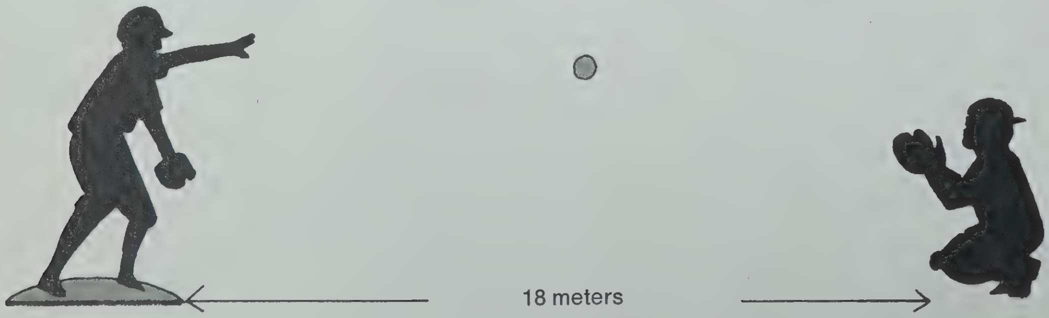
Distance traveled: To find the distance traveled, take the original distance from Ascención, 260 kilometers (km), and subtract the final distance from Ascensión, 160 kilometers.

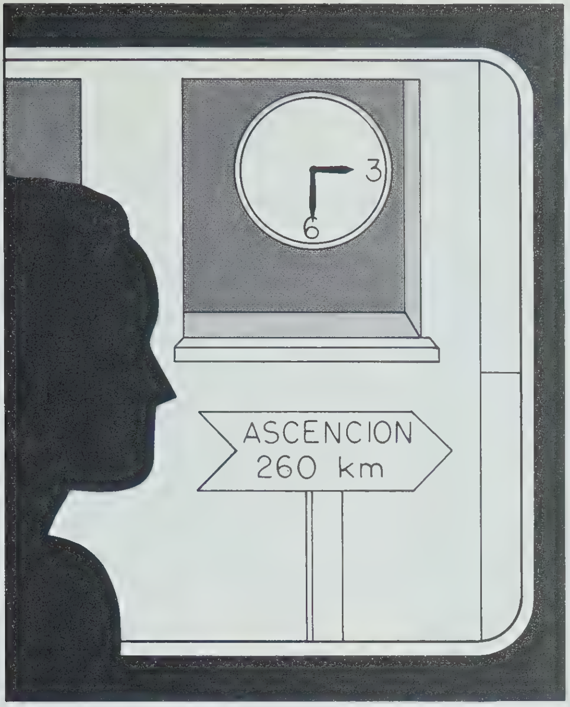
$$\text{distance travelled} = 260\text{ km} - 160\text{ km}$$
$$= 100\text{ km}$$

Time interval: To find the time interval, subtract the original time from the final time:

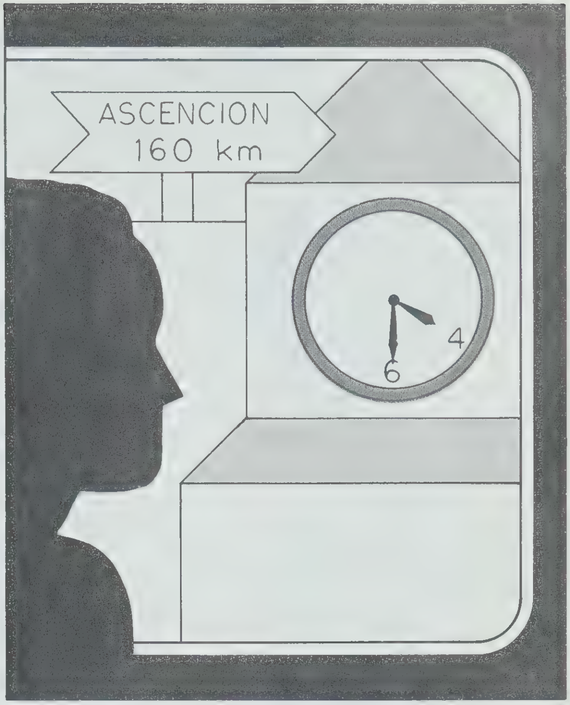
$$\text{time interval} = 4{:}30 - 3{:}30$$
$$= 1\text{ hour}$$

You now know that it took you one hour to travel a distance of 100 kilometers. So the bus has been cruising along at an average speed of 100 kilometers per hour. You can now do some rapid mental arithmetic by multiplying the 100 kilometers by 0.6. (See Appendix A, Chart II for more on the metric system.) Then you can say to the man,





9·3a



9·3b

"Our average speed over the last hour has been 60 miles an hour."

Does the value you get for speed mean the bus moved at a speed of 100 kilometers per hour every moment of the entire hour? It might.

The road might have been good and there might have been very little traffic. So the bus driver might have had no trouble driving along at an unchanging speed. In that case, you would have been moving along at 100 kilometers an hour at, say, 4:03, or at 3:48, or any other time during the hour.

On the other hand, you might have stopped for a red light or slowed down when the road got crowded. Then you might have moved faster the rest of the time. In either case, your average speed for the hour would have been 100 kilometers per hour.

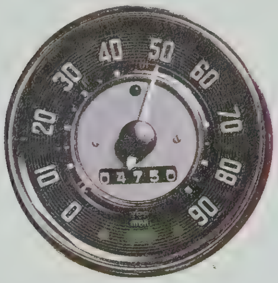
But you do not know *exactly* what the bus's speed was at, say, 4:00 if you haven't been traveling at an unchanging speed. To give the exact speed at any one instant, the Mexican bus and most other vehicles have speedometers.

In summary, you can find the *average speed* of any object over a certain time interval and a certain distance, whether it has a speedometer or not.

The method is always the same: Average speed = the distance traveled divided by the time interval.

If you know the object has been moving at an *unchanging speed* during the entire time, this average speed is also the exact speed for any instant during the interval.

9·4 The speedometer was photographed each time the driver changed speeds on a 50-mile trip. What was the average speed in miles per hour and in kilometers per hour for the entire trip?



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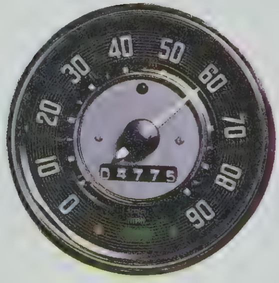

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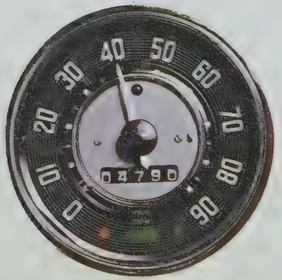

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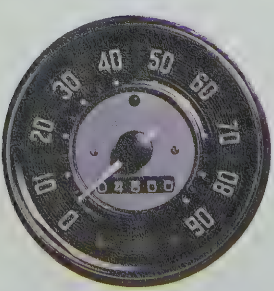


3:00 p.m.

TEST YOURSELF

1. *a) Name a property of a moving object.*

   b) Define speed using the words distance *and* time.

2. *A girl leaves school at 3 o'clock and starts walking home. Her house is 2 kilometers from school. She walks without stopping and without slowing down. She gets home at 3:30. How fast was she walking at 3:15? What was her average speed?*

3. *Another student who also leaves school at 3 o'clock and has 2 kilometers to walk gets home at 4:30. But this student had to stop at several traffic signals on busy streets. He also stopped at a friend's house on the way. What was this student's average speed from school to home?*

ON YOUR OWN

The earth in motion

The circumference of a circle can be found by multiplying its diameter (the distance across its center) by 3.14.

The earth's diameter is about 12,800 kilometers. The earth rotates on its axis once every 24 hours. How fast would you be rotating at the equator?

How great the thud?

Baseballs move too fast for us to measure their speed accurately without special photo equipment. So consider the slower-moving bowling ball.

Many bowling balls have the same diameter and smooth outer surface. Just by looking at two such bowling balls, could you tell which would have the greater thud, that is, be harder to start and stop?

You could do an experiment to find out. You would need help to start two bowling balls rolling toward you at the same speed. To get the balls going at the same speed, the other people can let the balls roll down a slope at the same time and from the same height. When the balls get to your hands, you will be able to tell which has more thud.

In the experiment (figure 9·6), the ball on the right hit with a greater thud. Just to make sure, though, you would want to try it again.

Again the balls should be let go down the slope at the same time and from the same height. If they come down the alley together, always across from each other, you can see that they have the same speed.

9·6a

9·6b

9·7

Once again, the same ball sounds a much louder and harder thud when it hits your outstretched hand.

You now have a way of comparing the thud of two rolling bowling balls. It is a good, sound method. But it has a very narrow range of application.

Then, between experiments, you might discover something new: When you pick up the stopped bowling balls to return them, the ball on the right, the one with greater thud, is harder to lift. Standing there with both bowling balls, your right arm feels more of a strain.

To check out this chance observation, you could run many tests with many pairs of bowling balls.

The one that has the greater thud always gives your arm the greater strain. And when two bowling balls of the same speed have the same thud, they seem to balance when you lift them—each causing about the same strain on your arms.

So now you seem to have two properties, thud and strain. They seem to correspond perfectly. A bowling ball that causes greater strain (when you lift it) will also produce a greater thud when it hits.

Because of this observation, you have a new ability: You can *predict* which of two bowling balls (when moving at the same speed) will have greater thud when they roll to a stop. And you can do this *without* rolling them! You can simply hold them still and sense which gives you the greater strain.

You will no longer need to take up a whole bowling alley to measure the thud of bowling balls. You can now get the answer you need in no more space than it takes to stand with a bowling ball in each hand.

With just these experiments with bowling balls, you might not want to make any sweeping generalizations about strain and thud. As it turns out, though, countless experiments with a variety of objects have supported this relationship between strain and thud.

For everyday purposes, these two properties give the same comparative values for any two objects. And a name has long been shared by both of them: *mass.*

When you *compare* the thud of two bowling balls, or their strain, you are in each case comparing their masses. This property, mass, is what determines both how hard an object is to start and stop, and, in a slightly different way, how hard it is to hold above the ground.

What is mass and what isn't it?

We now have another name for the "thud" property of moving objects. It's *mass*. But an object doesn't need to be moving for us to find out about its mass.

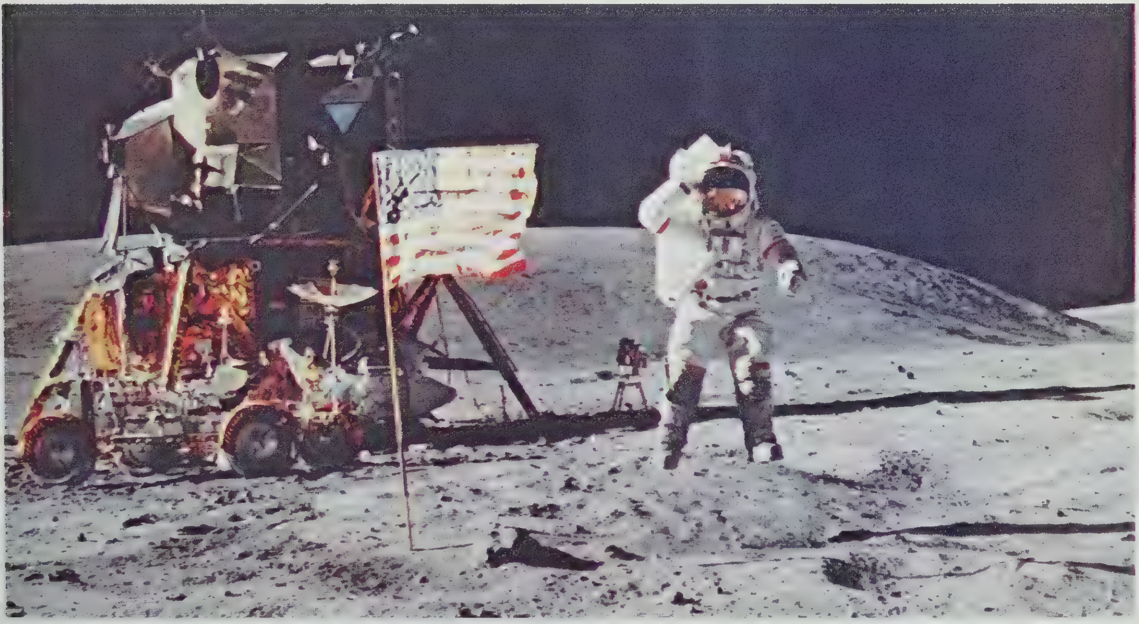
At first glance, it might seem that the mass of an object is the same as what you usually call "weight." But mass and weight are not exactly the same.

Weight is a measure of the attraction between the earth and objects near it. The amount of attraction *depends* on the masses of the earth and the object near it.

The greater the mass of an object, the stronger is the pull of the earth on it. On the other hand, the moon, which has a smaller mass than the earth, will pull less strongly on the same-size object. So, the object will weigh less on the moon than on the earth.

Weight also depends on other things, such as the distance between the center of the earth and the object. For example, the weight of an object is a litte less on top of a mountain than at sea level.

Weight decreases even more as an object leaves the earth, until, at a great distance from the earth, objects act almost as if the earth did not attract them at all. They are almost "weightless" in relationship to the earth.



9·8 The astronaut can take large jumping steps on the moon because it does not attract him as strongly as the earth did. He weighs less on the moon, but his mass is still the same as it was on earth.

But, while a bowling ball would have different weights on the earth, in space, and on the moon, its *mass* would be the same in all these places.

As long as the make-up of the bowling ball does not change, it will be just as easy—or hard—to throw and catch a bowling ball on earth, on the moon, and in space. If you have one value for an object's mass, that value will be good anywhere.

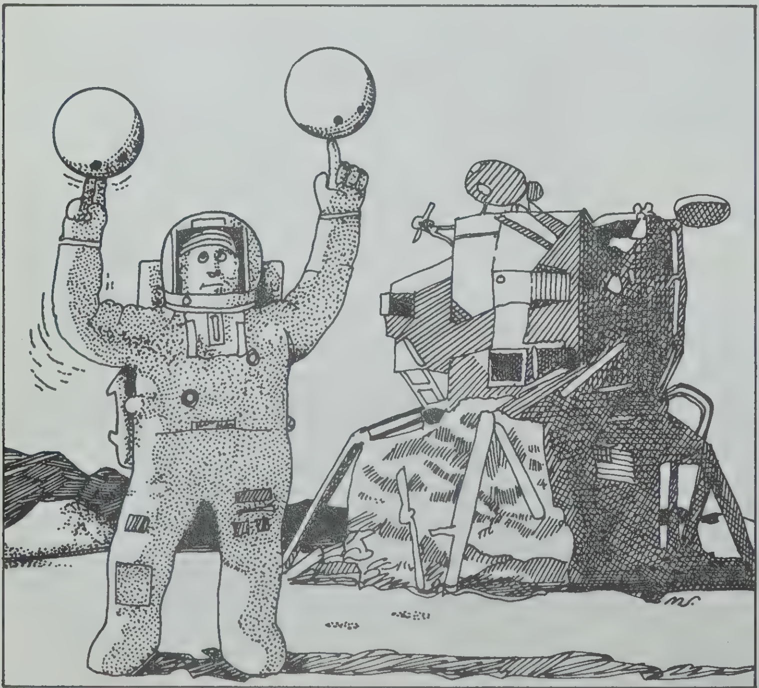
Up to this point, all you have looked at is a method for comparing two masses. Knowing that one bowling ball's mass is greater than that of another bowling ball is not the same as knowing the exact mass of either ball.

You could try to memorize the strain one bowling ball puts on your arm. Then when you lifted another bowling ball, you could compare its strain to the strain that you had memorized.

Then you could say, "When I lift this bowling ball, it gives twice the strain on my arm as my memorized bowling ball. So it has a mass of 2." Or you could say, "This one gives only half as much strain, so it has a mass of one half."

Even if you were standing on the moon lifting bowling balls, the relationship between these same bowling balls would still be the same. One would still strain your arm twice as much as your "memorized" bowling ball. And the other would still strain your arm half as much. However, they would *all* strain your arm less than they would on the surface of the earth.

You could improve your accuracy by actually carrying around a bowling ball for comparison, using it as the standard. But this method still lacks something in the way of accuracy.



9·9

There is an instrument of simple design that can be used to compare masses more accurately. It is an *equal-arm balance* (figure 9·10). The arms, with their pans for holding objects, are very carefully balanced when empty. The needle, placed at a right angle to the arms, points straight up or down to a fine line on the upright support.

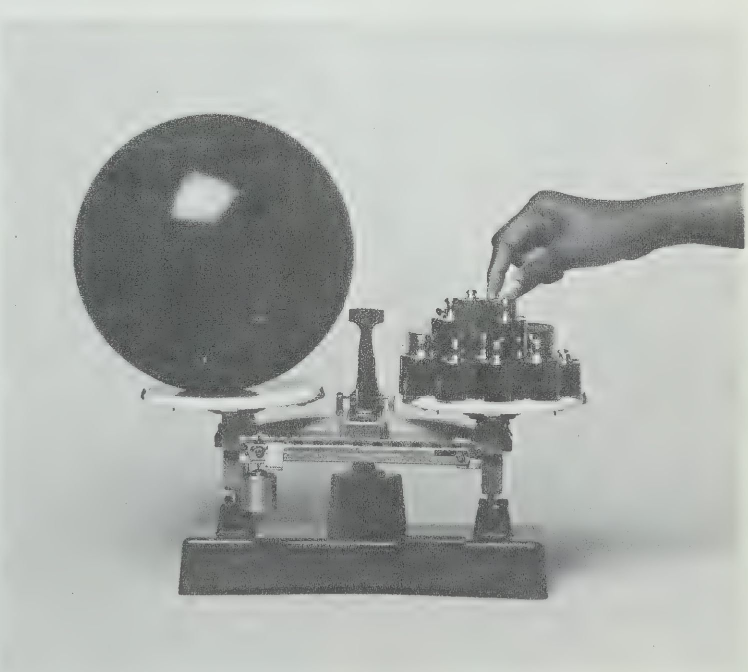
If you put an unknown mass on one side, and start putting masses which have assigned values on the other side, the needle will again point to the balance line only when the masses on each side are exactly equal. So you just start putting your standard bowling balls on the empty side . . .

A bowling ball is a rather awkward standard. But until less than 200 years ago, there was no standard mass (accepted by all countries). Then, in 1795, a standard mass was defined and agreed upon. It was called a *gram*. It was defined as the mass of one cubic centimeter of water at a temperature of 4° Celsius. (The meter and the Celsius scale were defined around the same time.)

Little cubes filled with cold water are not much easier to carry around than bowling balls. Therefore, small metal blocks were made that balanced exactly with the standard gram of water.

The gram is a very small mass. It takes five gram masses to balance one United States nickel. In everyday life a larger unit of mass is much more practical. So a thousand-gram mass called a *kilogram* (*kilo* is Greek for thousand) has become the international standard mass. The kilogram is the standard measurement used in exchange of goods and information between nations.

A precisely measured block of platinum with a mass of exactly one kilogram is kept in a vault at the International Bureau of Weights and Measures at Sèvres, France. In fact, it is this block, rather than an amount of water, that is now the actual standard for the kilogram.



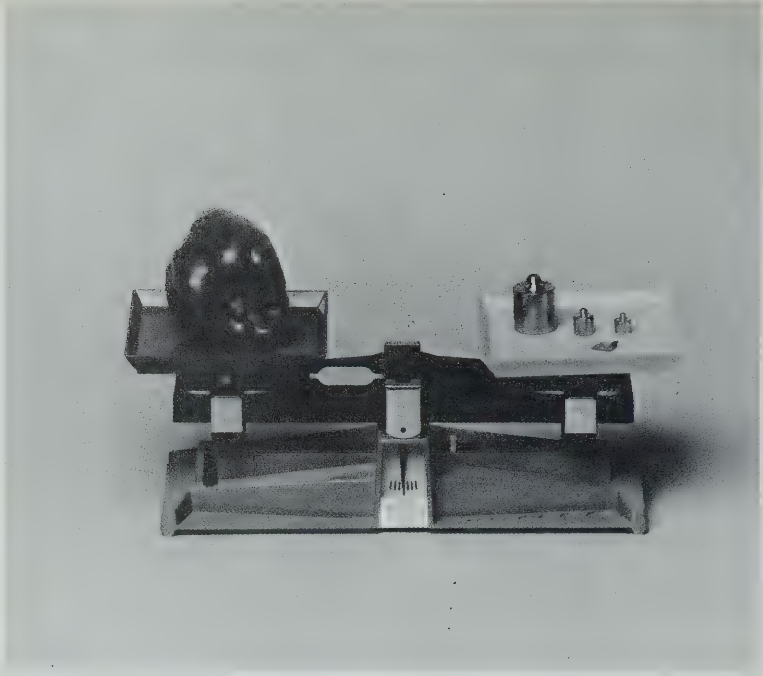
9·10 The mass of the bowling ball is 4 kilograms.

Each nation has copies of the block. The United States keeps its copy at the National Bureau of Standards in Gaithersburg, Maryland. Like the original in Sèvres, the United States copy is kept in a vault, safe from the effects of air, water, heat, or cold.

For measurement purposes in science and in trading between countries, many other groups have their own standard masses. All of these are kept carefully in accord with the international standard.

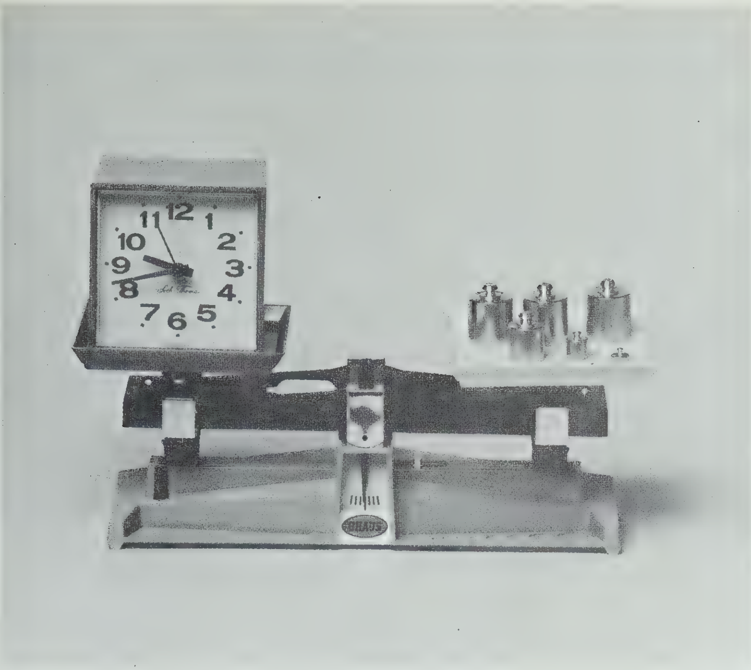
TEST YOURSELF

1. *How is "mass" different from "weight"?*
2. *Describe two ways to compare the masses of two bowling balls.*
3. *Which of the following could be compared by using the moving (thud) method of mass comparison, and which could be compared by using the stationary (strain) method? If both methods can be used, indicate which would be easier.*



9•11a The mass of the green pepper is 116 grams.

9•11b The mass of the nickel is 5 grams.



9·11c The mass of the clock is 363 grams.

9·11d The mass of the whiffle ball is 45.5 grams.

Describe in each case how you would go about using the method chosen.

a) two red wagons
b) two sacks of mail
c) two grand pianos on wheels
d) two small children on roller skates

4. *What is the definition of the* gram?

5. *What is the definition of the* kilogram?

6. *Indicate, for each of the following, whether you would probably measure its mass in grams or in kilograms:*

   a) a pencil
   b) yourself
   c) a glass of water
   d) a tank of water

Another look at the measurement of time—essential to the measurement of motion

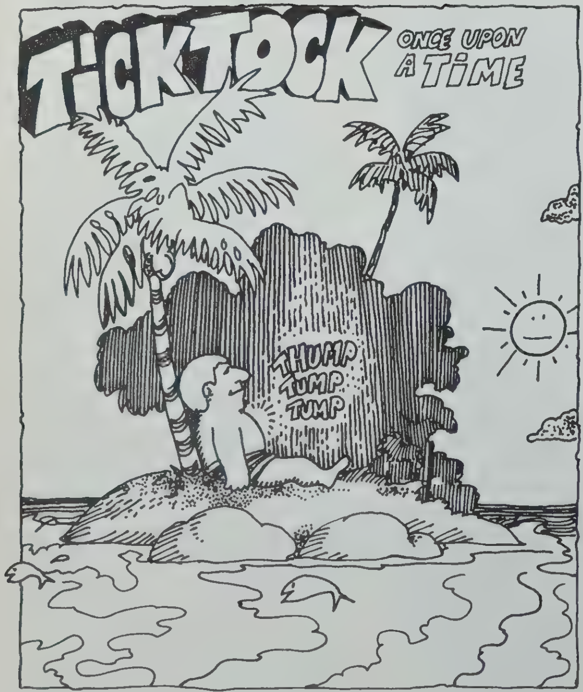
Tick Tock

Once upon a time

Imagine that you have just awakened on a lonely island after a long sleep. You have no memory, no sense of time.

As you lie on your back in the warm sand, not moving, your eyes focus on one swaying palm tree. Besides the warmness of the sand and the sun, you feel a thumping in your chest as one heartbeat follows another. You also feel the gentle flow of air as you breath in-and-out, in-and-out, in-and-out. You are alive and aware of the repeating events of some personal inner clocks.

You begin to feel too warm in the sun so you get up slowly. But not quite. You find yourself on the sand again. Your knees are weak from lack of use. You try again. After a few steps you feel more sure. You begin to explore the island and your awareness shifts from yourself to things happening around you.



Man it's Hot! when will it cool DOWN?

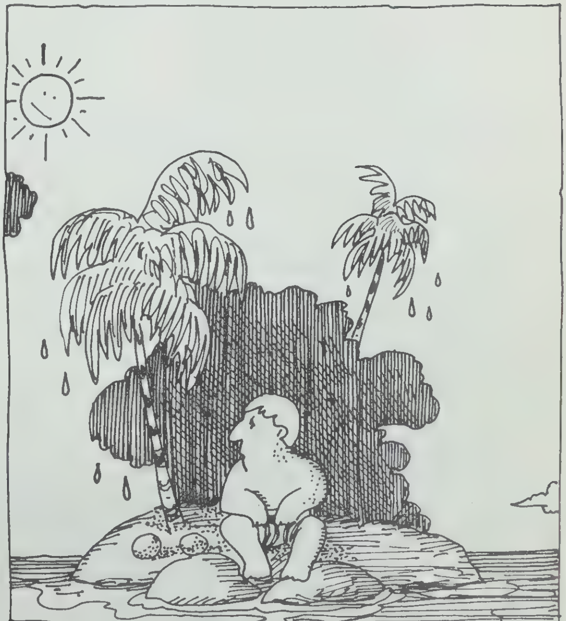
Dark clouds slide in and block out the sun. A wind begins to blow. And the waves wash higher and higher onto the beach. A quick tropical storm soaks you completely. Small animals scurry for the protection of their nests. Then the wind dies down and the sun comes out again.

By thinking back over the events in the order in which they happened, you begin to develop an idea of time.

Slowly a fear begins to grow within you as stillness creeps over the island. The sun sinks into the ocean, and you're swallowed by darkness. Huddling between some large boulders, you fall asleep. The next thing you feel is the warmth of the sun. And again you open your eyes to the bright world of the tropical island.

You continue to explore your island, this time in search of food. You learn which animals you must stalk slowly, which animals

Where did that Storm come from?



you must chase swiftly, and which animals you must run from frantically. As you compare the fast and slow movements, you get another idea of time.

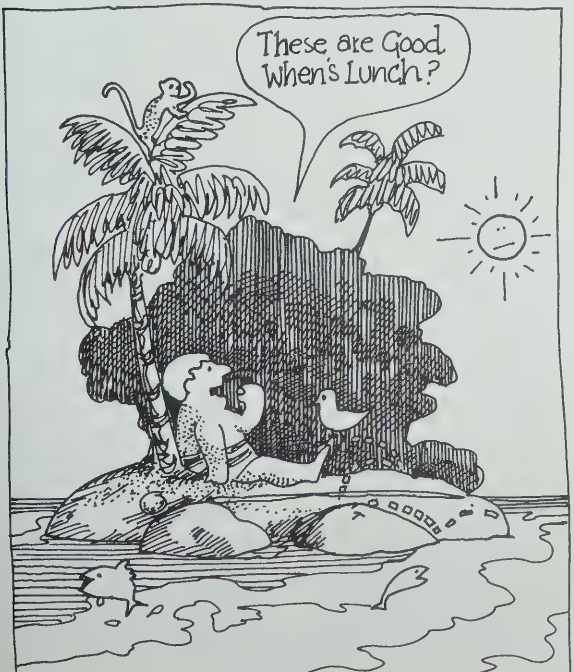
Suddenly that terrible event is happening again. The sun sinks into the ocean and darkness again closes around you. This time, though, you find a cave. You feel more protected, so you settle down to sleep more quickly. Instead of trembling with fear until you fall asleep, you are hoping that light will again follow the darkness.

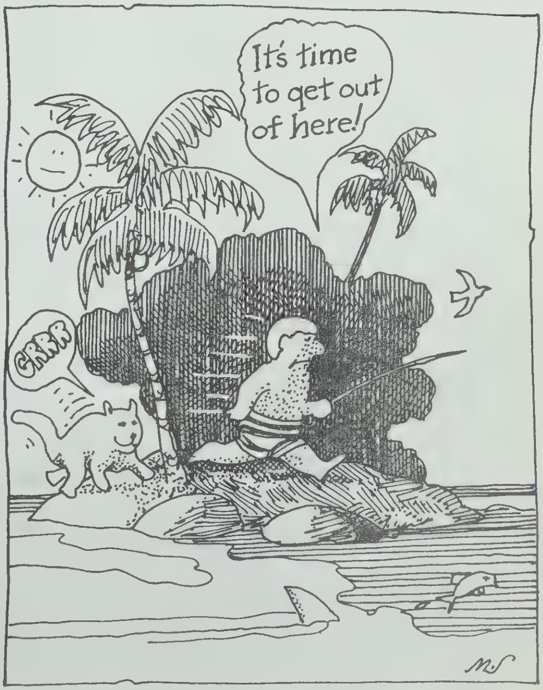
After you have lived through many day-night-day cycles, you begin to rely on this clock of nature. You learn that you can determine distances to places on the far side of your island in terms of the number of days and nights it takes to reach them.

Darkness is no longer something to be feared. You spend part of each night studying the sky. You notice that over a period of many nights the moon seems to change shape. As you continue to watch the moon, you see that the shapes repeat themselves every twenty-nine nights. You have discovered another clock of nature.

For living on your tropical island, your ideas about time are good enough by now. They are good enough for hunting, fishing, and picking berries.

The ideas of past and present, the order of events, fast and slow motion, day-night cycles, and the repeating changes of the moon are all the time sense anyone needs who lives as simply as you do on your island. And that's all the time sense people anywhere had until about 4000 B.C. That's when the ancient Egyptians saw a need for another way to measure time.




It's time to get out of here!
GRRR
M.S

Progress

The ancient Egyptians looked forward to the yearly floods of the Nile River. The floods brought water and nutrients for their desert land. Because the Egyptians wanted to plan the planting of their crops, it was important to them to be able to tell exactly when the river would flood.

They had made up a calendar according to the changes of the moon. But they found that they could not predict the flooding very well this way.

They came up with a solution. They had noticed that the Nile always flooded at the same time as the Dog Star (Sirius) rose in the east just before daybreak. After closer observation, they found that the Dog Star appeared at that same place in the sky every 365 nights. They had discovered another natural clock. They made up a new calendar which had 365 days. By using this calendar, they could successfully predict when the Nile would flood.

More progress

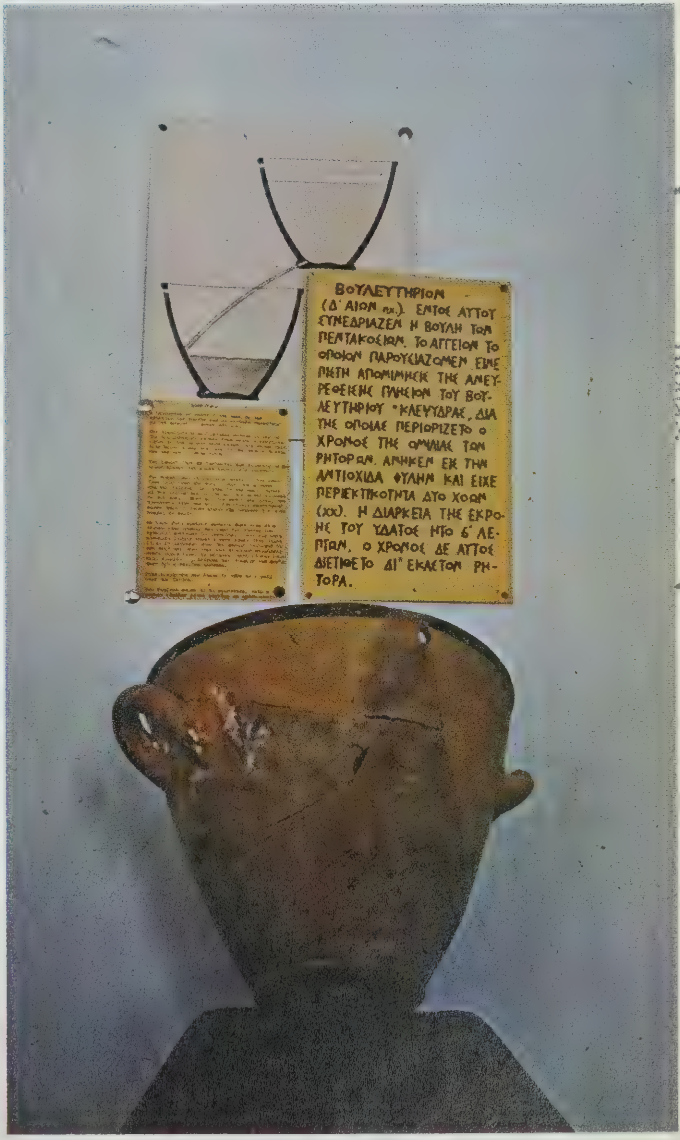
Besides keeping track of the passing of days, people needed shorter time spans measured. Such was the case especially as business and government activities became more and more complex.

One of the most obvious ways was again related to the sun and what seemed to be its circular path through the sky. The Egyptians and other ancient people had noticed that the shadow of an object changes as the sun moves through the sky from sunrise to sunset. From this idea came the sundial. At first, it was just a stick in the ground, whose shadow was measured during the day to indicate the time of day.

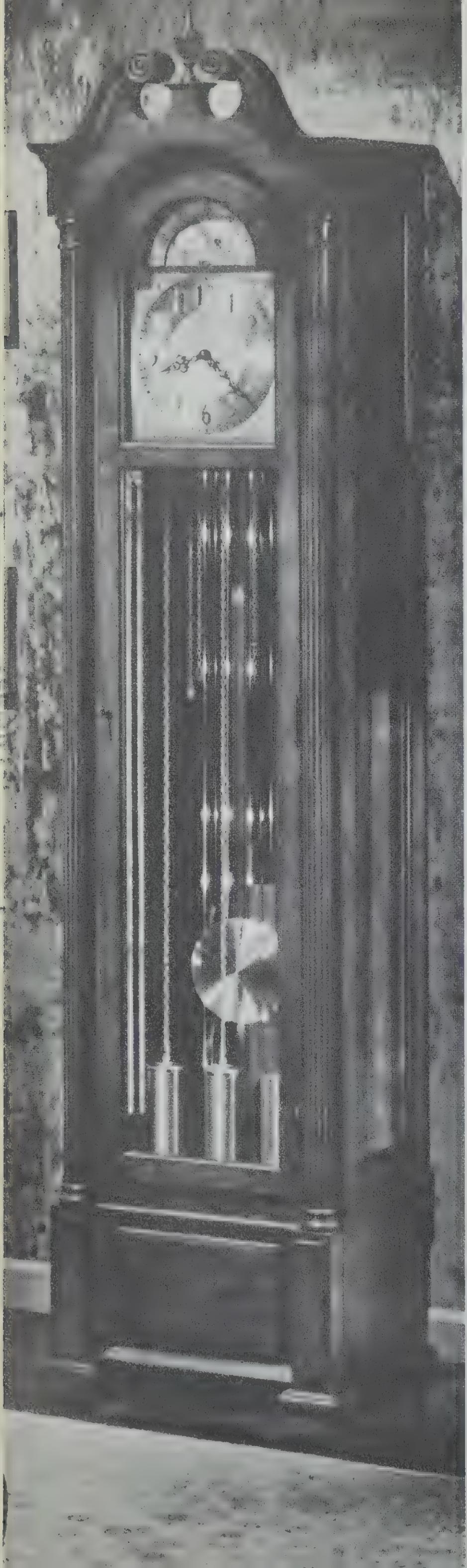
There were many variations on this idea. The Egyptians in particular kept up their habit of doing things in a big way. They built huge brick columns called obelisks. The Egyptians measured the shadows of the obelisks, using them as huge sundials.

People found another way to measure time—the water clock. It works very simply. Water drips slowly from an opening in a jug. The opening and the amount of water in the jug were adjusted so that the water dripped at a steady rate.

9•13 Obelisk at Heliopolis, Egypt.


ΒΟΥΛΕΥΤΗΡΙΟΝ
(Δ' ΑΙΩΝ π.Χ.) ΕΝΤΟΣ ΑΥΤΟΥ
ΣΥΝΕΔΡΙΑΖΕΝ Η ΒΟΥΛΗ ΤΩΝ
ΠΕΝΤΑΚΟΣΙΩΝ. ΤΟ ΑΓΓΕΙΟΝ ΤΟ
ΟΠΟΙΟΝ ΠΑΡΟΥΣΙΑΖΟΜΕΝ ΕΙΝΕ
ΠΙΣΤΗ ΑΠΟΜΙΜΗΣΙΣ ΤΗΣ ΑΝΕΥ-
ΡΕΘΕΙΣΗΣ ΠΗΛΙΝΗΣ ΤΟΥ ΒΟΥ-
ΛΕΥΤΗΡΙΟΥ "ΚΛΕΨΥΔΡΑΣ, ΔΙΑ
ΤΗΣ ΟΠΟΙΑΣ ΠΕΡΙΟΡΙΖΕΤΟ Ο
ΧΡΟΝΟΣ ΤΗΣ ΟΜΙΛΙΑΣ ΤΩΝ
ΡΗΤΟΡΩΝ. ΑΝΗΚΕΝ ΕΙΣ ΤΗΝ
ΑΝΤΙΟΧΙΔΑ ΦΥΛΗΝ ΚΑΙ ΕΙΧΕ
ΠΕΡΙΕΚΤΙΚΟΤΗΤΑ ΔΥΟ ΧΟΩΝ
(ΧΧ). Η ΔΙΑΡΚΕΙΑ ΤΗΣ ΕΚΡΟ-
ΗΣ ΤΟΥ ΥΔΑΤΟΣ ΗΤΟ 6' ΛΕ-
ΠΤΩΝ, Ο ΧΡΟΝΟΣ ΔΕ ΑΥΤΟΣ
ΔΙΕΤΙΘΕΤΟ ΔΙ' ΕΚΑΣΤΟΝ ΡΗ-
ΤΟΡΑ.

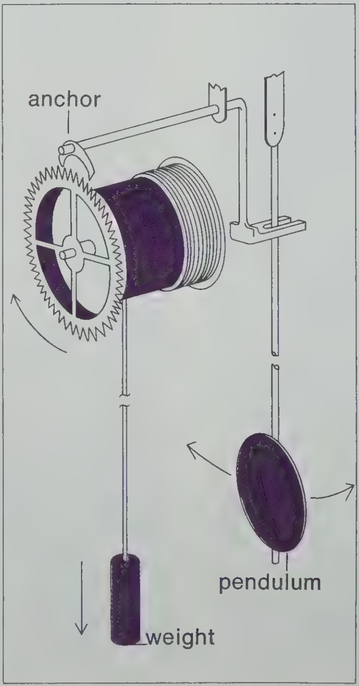
9•14 Water clock. Agora Museum, Athens, Greece.



9·15a A grandfather clock with pendulum

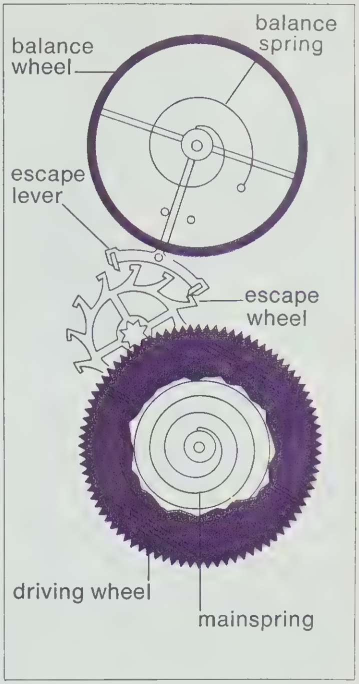
The Greeks and Romans improved upon the water clock. Probably one of the reasons was to limit the length of speeches in public places. As water emptied from one container into another, their improved water clock turned hands on a clock face. Systems of chain-connected floats on the changing water surfaces caused this motion.

Sand clocks were based on an idea similar to that of water clocks. Sand was put into a container with two sections, one above the other. The sand in the upper portion of the container would empty at a steady rate into the lower portion. When all the sand from the upper portion had emptied into the lower portion, the container was turned over and the whole process would begin again. Complicated forms of the sand clocks used systems of sand baskets attached to chains. As the sand buckets filled, the chains moved large hands on clock dials.



9·15b The energy of motion for turning the hand of a pendulum clock is produced by a very slowly falling *weight*. The purpose of the *pendulum* is to regulate the rate of the clock movements. The even back-and-forth motion of the pendulum causes the *anchor* to rock back-and-forth evenly. The anchor motion controls the falling weight and the rate at which it moves the gears that move the clock hands.

9·16a Pocket watch



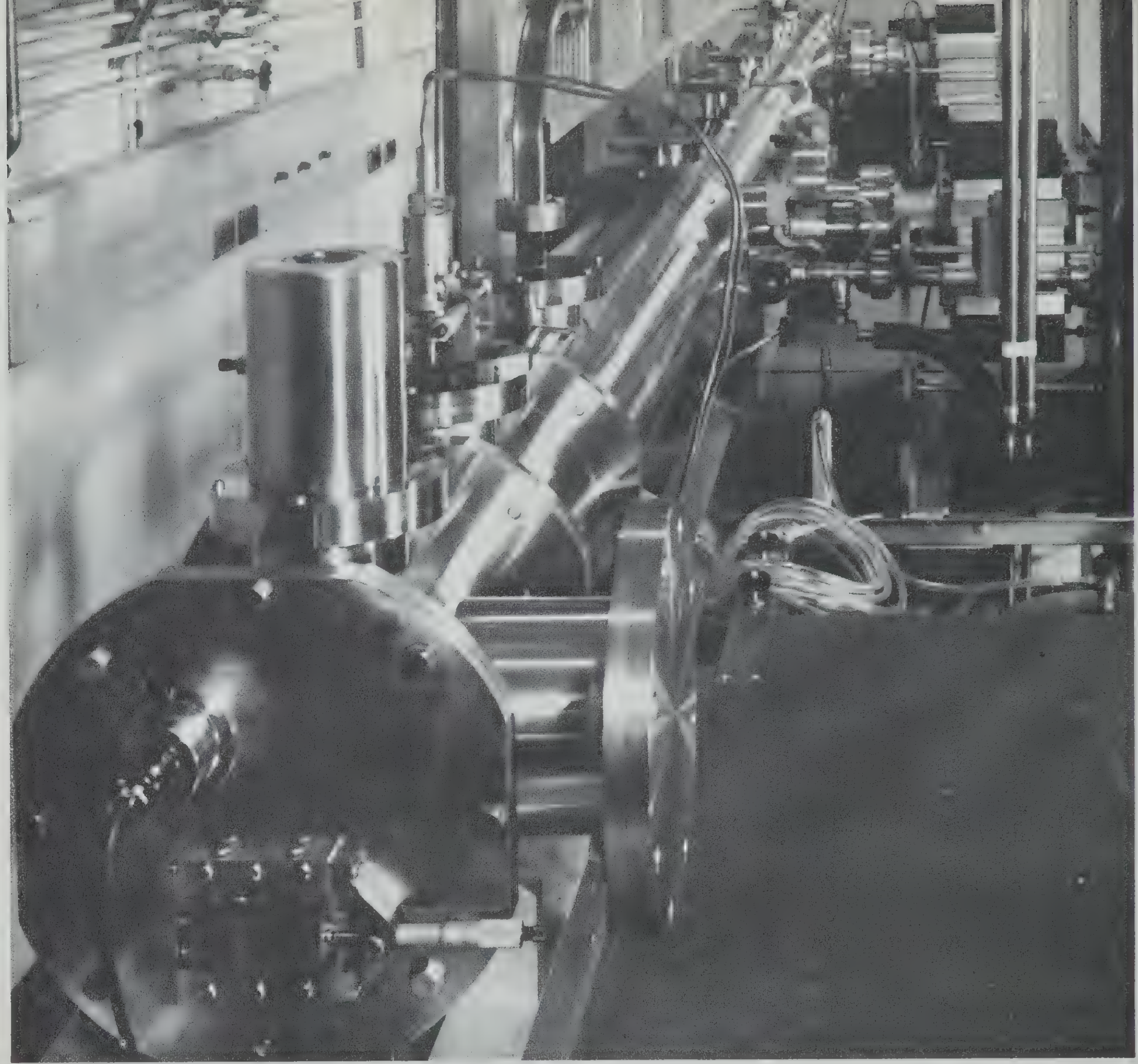
9·16b The wound-up *mainspring* provides the energy of motion for the hands of most watches. But that energy must be regulated. The even winding and unwinding of the *balance spring* moves the *balance wheel* back-and-forth. This motion rocks the *escape lever*, thereby allowing the *escape wheel* to move forward evenly. The escape wheel controls the energy of the unwinding mainspring so the hands of the watch will also move forward evenly.

Ways of measuring the passing of time were improved upon even more in the 1500's and 1600's, when scientists began to make accurate observations of motion. One such scientist was the famous Italian, Galileo.

Still more progress

There is a story about the way Galileo got his idea for improving upon clocks. It was during a service in a large cathedral. Galileo's eyes wandered to a chandelier swinging back and forth on a long chain. The chain was attached to the cathedral's high ceiling. Using his pulse (personal clock) as a timer, Galileo found that the chandelier was swinging back and forth in equal time intervals. His idea of the regular motion of swinging objects was used to make the pendulum clock. Clocks which were based on systems of weights and pulleys already existed. But they were not very accurate. Galileo's addition of a pendulum (a weight swinging on a string or chain) made these clocks much more accurate.

This same kind of regular motion is supplied by the balance wheel and spring in a modern watch or mechanical clock. As the spring uncoils, it keeps a tension on the gears to keep them moving. The balance wheel vibrates back and forth at regular intervals. So the gears and the clock hands keep moving at specific rates.



9·17 Atomic clock

Electricity has provided another way to keep time. The electricity supplied to most homes in the United States changes direction 120 times each second. This 60-cycle vibration keeps the gear systems of electric clocks turning very evenly. But even these timers must be checked and corrected regularly against the turning of the earth, a natural clock.

The split-second timing that is necessary in space flight demands even more accurate time measurements. Scientists and engineers have designed devices called "atomic clocks" for this purpose. These timing devices use the vibration of certain atoms and are accurate within a one-second variation in a hundred years. All in all, time sense and time measurement have come a long way.

ON YOUR OWN

Your personal clock

Use your own ever present timing device to measure relative time intervals. By pressing the tips of the fingers against the artery on the right side of your throat, you can use your own pulse rate as a timing device.

By counting pulse beats, you can compare the lengths of songs on records or radio, telephone conversations, or parts of sports events.

By the way, is your pulse rate always the same?

ON YOUR OWN

A swinging clock

You can count pendulum swings to compare various time intervals. A pendulum is a mass suspended by a string or a chain from a fixed point. Almost anything can be used for a mass: keys, a ball, a bolt, a small hammer, etc.

Test to see that the pendulum is attached so that it can swing freely. Then start its swinging.

How is the rate of pendulum swings affected by the size of the mass? by the length of the string? by how high the mass swings?

The metric system of measurement and its international use

How Much Depends on Where

What's the speed limit for cars in your town? That probably seems to be a simple question. But before you can answer that question, you have to know who is asking it. Your neighbors will know what you mean if you answer 30 miles an hour. Anyone from Canada will understand you. And a Britisher will, too.

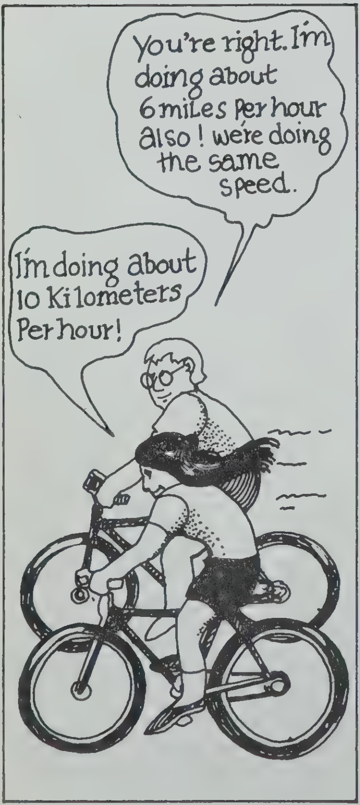
But a Mexican friend will have some trouble figuring out whether 30 miles per hour is fast or slow. A German will have the same problem, as will a Russian, most Africans, all Scandinavians, almost all Asians, and most Europeans. This list will probably include the English a generation from now since they are in the process of changing over to the metric system.

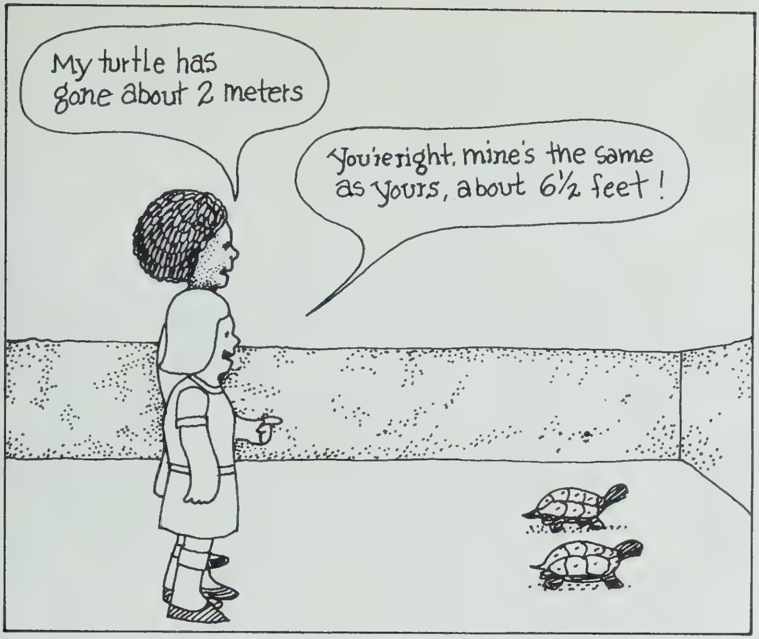
In fact, the United States is one of the last countries left that measures things in miles, feet, pounds, and gallons. Most of the other countries mentioned above use the *metric system*. With this system, things are measured in kilometers, meters, kilograms, and liters.

What are some advantages in measuring things in kilometers, meters, kilograms, and liters? Everything in most of the world's everyday life is measured in metric units. Whereas, in the United States, we are still measuring people by the pound; butter by the pound (same pound); cream by the pint; strawberries by the pint (different, dry measure pint); milk by the quart; jars of food by pounds, and ounces, and parts of ounces; medicine in fluid ounces; pears by the peck; wheat by the bushel; oil by the barrel; gas by the gallon; land by the acre; surveys by the rod; buildings by the foot; highways by the mile; and manufactured goods by the inch, the eighth inch, and the tenth inch. There are also the gills, fifths, statute miles, nautical miles, short tons, long tons, scruples, drams, magnums, links, chains, furlongs, hands, and leagues dragged out for special occasions or special trades.

And none of these measurements that surround us and confound us has ever been made legal! Congress was given power in the Constitution to regulate weights and measures. But it never legalized any of these "customary" measures.

Thomas Jefferson and George Washington both urged the new government to adopt a standard system. Jefferson suggested that


You're right. I'm doing about 6 miles per hour also! we're doing the same speed.
I'm doing about 10 Kilometers Per hour!


My turtle has gone about 2 meters
You're right, mine's the same as yours, about 6½ feet!

9·20

a decimal system be used. In a decimal system, all units are related to each other by factors of ten. Our coins, for example, were made decimal by Congress:

10 mills = 1 cent   10 cents = 1 dime   10 dimes = 1 dollar

We don't use mills anymore. But cents, dimes, and dollars are going strong. Adding or subtracting money is easy. Compare the rest of our "system" of measurement:

12 inches = 1 foot
3 feet = 1 yard
5280 feet = 1 mile
1760 yards = 1 mile

272¼ square feet = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile

8 ounces = 1 cup
2 cups = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon

16 ounces = 1 pound
2000 pounds = 1 ton

2 pints = 1 quart
8 quarts = 1 peck
4 pecks = 1 bushel

Not a ten anywhere in sight! How many of these equivalents do you know by heart? Chances are that ten years from now you'll know even fewer than you do now. Few adults know them all.

Yet long ago we had the chance to adopt a ready-made decimal system of measurement. Since 1795, the French had been officially using their metric system. The French system had been pushed into law following their Revolution of 1789.

At that time, France needed a simple system even more than we did. Before the French Revolution, over 200 different units were in use there. These measures had often been changed by the king or the ruling class. Whenever tax money became low, the simplest solution was to increase the measuring standard to increase the take, or decrease the measure to make a person's taxable goods seem more than they really were.

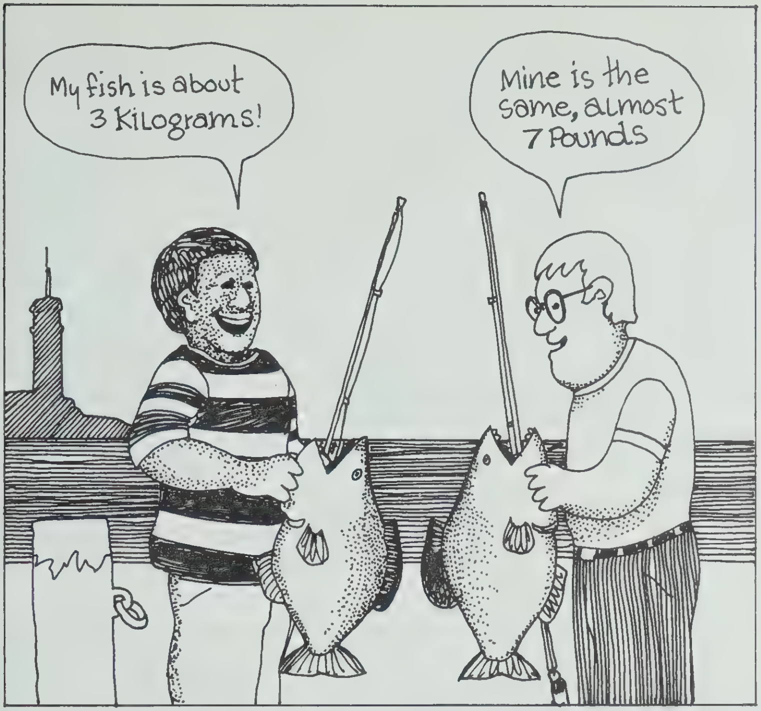
The planners of the new system of measure wanted a scientific, unchanging basis for it. They chose one ten-millionth of the distance from the North Pole to the equator as the standard for length. This distance was named the *meter*. (The standard for mass was going to be the mass of cold water that would occupy a cube one-hundredth of a meter on each side.)

Back in the United States, in 1817, John Quincy Adams joined Jefferson, Washington, and others. He did a serious study of the units in use at the time. He found over eighty of them and declared the whole collection a disorderly hodgepodge. He urged Congress to do something, the sooner the better. He too suggested a system based on a unit of ten.

The furthest Congress got was to pass a law in 1866 declaring that it was legal to use the metric system. In fact, the metric system is still the *only* system that Congress has ever made legal. But being legal is not the same as being used.

At that time, it would have cost the nation very little to change to the metric system. Most of the people were still farmers. Rather few instruments and machines would have had to be changed.

By the turn of this century, the cost of going metric was much higher. Yet a law which almost passed in 1902 could still have saved us billions of dollars. That law would have required only government agencies to change to metric measures. Companies that supplied or worked with the government would also have needed to change. Others could have adopted the new standards


My fish is about 3 Kilograms!
Mine is the same, almost 7 Pounds

9·21

more slowly. But the metric debate turned into a name-calling, insult-hurling circus. So the person who had suggested the law withdrew the suggestion.

In the early 1970's the support that was really needed in 1902 came through. Congress voted for a three-year study of the pros and cons of changing to the metric system. The results of this study indicate that the United States should have a carefully planned government-supported program for making this change.

As for the overall effort involved, other nations have found that the change is slow, but not usually as slow as expected. In industry, machines with parts sized according to the old system will wear out. New ones with parts sized according to the metric system can be built to replace them.

People, too, can change. It's true that most people in the United States right now think a sack of potatoes should be 10 pounds and not 4 kilograms. They estimate a board as "around 6 feet," and not as "about 180 centimeters." And they are used to milk that comes in quarts, not liters. But once people have looked at and felt a lot of liters, centimeters, and kilograms, these units will become as natural as the inch, ounce, pint, and all the rest. It's possible that, in the near future, you'll be able to say to anyone on earth, "My height is 165 centimeters. What's yours?"

I'm 165 cm tall.
We're both 66 inches tall!

9·22

Every moving object has a mass and a speed. The values for these properties can be gotten from observed facts. Single moving objects, however, are not really the most interesting events. The real action occurs when objects meet: baseball with bat, hockey stick with puck, and, unfortunately, the bumper of one car with that of another.

Some basic ideas about motion apply in all these cases. A good place to get at some of these ideas is the bowling alley. We can have bowling balls bump into each other in the gutter of a bowling lane.

In order to arrange and study meetings of bowling balls, we will need to consider a few things about meetings between moving objects in general. In the study of motion, these meetings are called *collisions.*

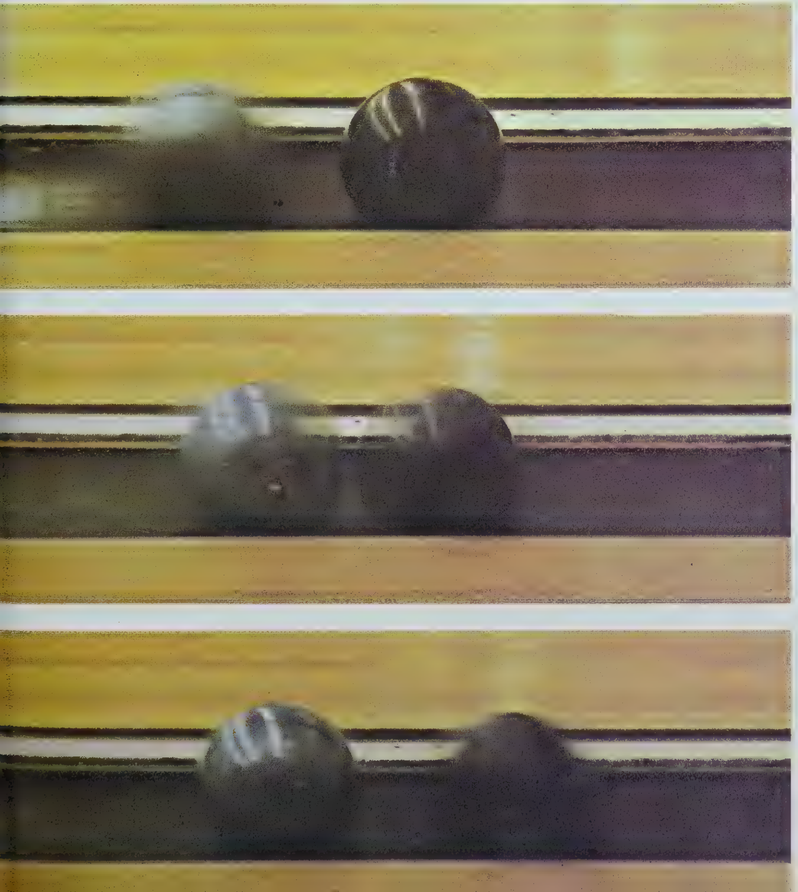
The collisions that will take place in the gutter of the bowling lane will be *straight-line* collisions. The balls will be kept to movement along the straight path of the gutter.

In addition, the collisions between bowling balls will be *elastic* collisions. "Elastic" in this case doesn't refer to the stretching of rubber bands. In an elastic collision, the objects that collide can bounce off each other freely without bending or sticking.

Another condition that will simplify our study of collisions is the smooth, hard, straight surface of the bowling-lane gutter.

However, even the best possible bowling-lane gutter will still have small uphill or downhill slants, bumps, holes, and rough patches. All of these will interfere with the collisions. Because special equipment is needed to account for these small variations, let's overlook them in our experiments. Let's assume that our collisions are ideal.

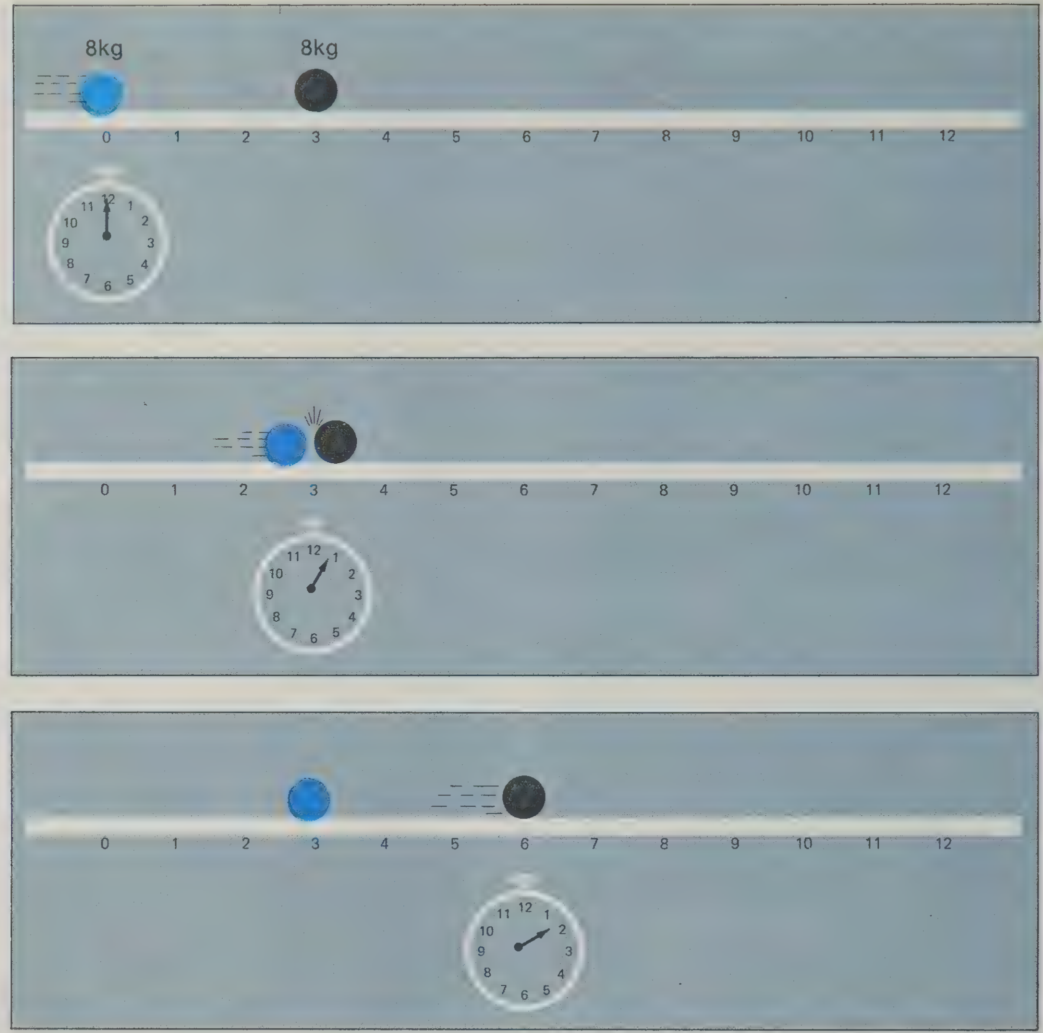
9·24 The boy lets the ball roll down the incline into the flat gutter, where it moves at a constant speed. Any ball allowed to roll down the same incline from the same height will move down the flat gutter at the same constant speed.



Basically, ideal collisions would be ones where the motion of the objects is affected only by the motion you give them, and by their short contact with each other. There would be no unaccounted influences that hinder motion or add to it. Under ideal conditions, you could set up the same collision again and again and get exactly the same results.

For our study of ideal collisions, let's start with two bowling balls of the same mass. The bowling balls should also have the same diameter.

One of the bowling balls, a black one, is placed in the middle of the gutter (figure 9·24). The other one, a blue one, is released from an incline placed at the start of the gutter. When the blue ball reaches the straight part of the gutter, it has picked up as much speed as it can. At this speed, it travels toward the black ball, which is not moving. The blue ball rolls into it and stops. The black ball moves on.

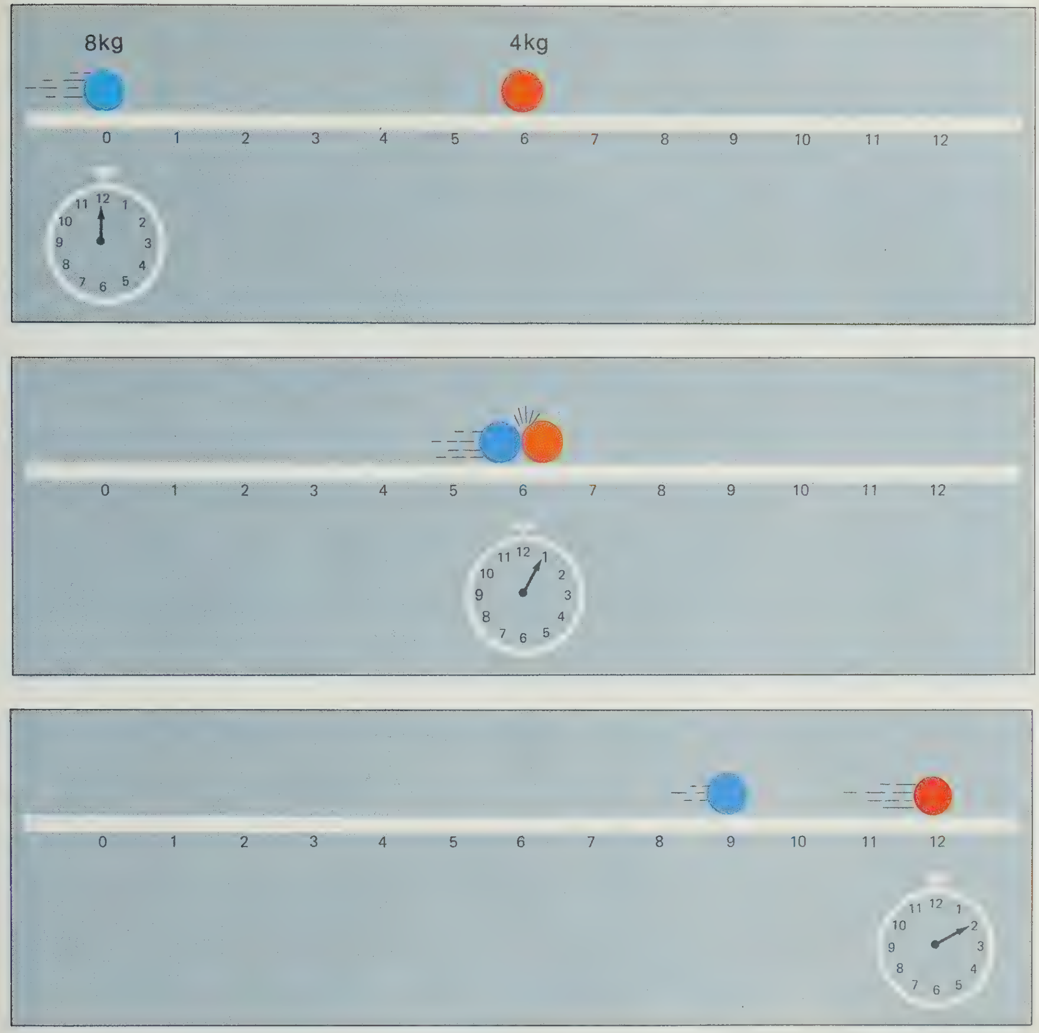


9·25

Assistants with stopwatches time the blue ball over a marked distance, before collision. They also time the black ball over a marked distance after the collision. With these measurements the speeds can be calculated.

What is the change in the speed of the black ball? What is the change in the speed of the blue ball? (See figure 9·25.) So far it seems that the speed lost by the blue ball is gained by the black ball during the collision.

But motion is not based only on speed. It is also affected by mass. We can change the masses of the balls involved in the collision to see what effect this will have on the results.



9·26

In the second experiment, one ball, a red one, has a mass only half that of the blue ball. But both balls still have the same diameter. The red one is placed in the middle of the gutter. The blue one is again released from the incline placed at one end of the gutter. But this time it is released from higher up so that the blue ball will have more speed than it did in the first collision experiment.

This time, instead of stopping, the blue ball keeps going at a slower speed after it hits the red ball (figure 9·26). Meanwhile, the red ball goes forward at the same speed as the blue ball had before the collision.

Table 1

	Before collision	After collision
Mass of blue ball	8 kg	8 kg
Mass of red ball	4 kg	4 kg
Speed of blue ball	6 m/sec	3 m/sec
Speed of red ball	0 m/sec	6 m/sec

This is no simple trade-off of speed. Table 1 shows the values for speed before and after the collision.

The combined speed of both balls before collision can be figured as follows:

6 m/sec + 0 m/sec = 6 m/sec
(blue) (red)

The combined speed of both balls after collision can be figured in the same way:

3 m/sec + 6 m/sec = 9 m/sec
(blue) (red)

The first impression you might have here is that some extra speed, 3 meters per second, came from nowhere in the middle of the collision. But you should be a little skeptical about the idea of getting something for nothing in a collision. After all, in the previous collision, you did not get any such "bonus" speed.

It seems that changing the mass of the bowling balls changes the collision. You can also see that changing the initial speed of the ball which hits the one sitting still will change the speeds that result from collision. (Compare figure 9·25 with figure 9·26.)

It appears that something is being transferred between the objects during collision. The amount of whatever is transferred depends on both the masses and speeds of the objects involved.

Since the transferred property is related to both mass and speed, a common way to analyze it is to examine the product of mass multiplied by speed. Let's do this for the objects in the second experiment (the case of the "bonus" speed). Now look at Table 2.

Take special note of the last line in Table 2. It shows the total amount, before and after collision, of the product that is found by multiplying the speed of the objects by their mass. As you can see, the total amount of this product remains unchanged. Perhaps this product actually gives the value of the property that is transferred in collisions.

A few more experimental results would begin to show that this result is generally true. The new property given by *mass × speed* is neither lost nor gained during collisions. There is no problem of "something for nothing," as there was when you added just the speeds of both bowling balls.

Once again, you have a property which needs a name. The accepted name for it is *momentum*. The momentum of an object is its mass multiplied by its speed: mass × speed = momentum.

Table 2

	Before collision	After collision
Mass of blue ball	8 kg	8 kg
Speed of blue ball	6 m/sec	3 m/sec
Mass × speed of blue ball	48 kg·m/sec	24 kg·m/sec
Mass of red ball	4 kg	4 kg
Speed of red ball	0 m/sec	6 m/sec
Mass × speed of red ball	0 kg·m/sec	24 kg·m/sec
TOTAL (mass × speed of blue ball *plus* mass × speed of red ball)	48 kg·m/sec	48 kg·m/sec

The idea that momentum is neither lost nor gained in a collision of objects has to be applied with care. In any real-life situation, all kinds of things interfere so that your calculations will not be exact. For example, the smallest bumps in the path on which an object is rolling will interfere with your measurements. The smallest twisting or turning of the moving object will also interfere. So will any imbalance in the mass of the moving objects. However, the momentum idea is useful because it will give you a general idea of what will happen to the motion of two objects when they bump into each other.

TEST YOURSELF

1. *What is momentum?*
2. *When two objects bump into each other, is any momentum lost or gained? Explain.*
3. *The speed of a car is 50 kilometers per hour. Its mass (passengers included) is 2,400 kilograms. What is its momentum? What is the car's momentum when its speed is increased to 60 kilometers per hour?*
4. *Two identical metal balls collide on a hard surface. The mass of the first ball is 1 kilogram. Its speed is 17 meters per second. The mass of the second ball is 1 kilogram, and it is not moving before the collision.*

   The momentum of the first ball is 0 after collision. What is the speed of the second ball, after the collision?
5. *One lab cart (*A*) is at rest. Another lab cart (*B*) bumps into it at a speed of 3 meters per second. Cart* A *has a mass of 2 kilograms. Cart* B *has a mass of 3 kilograms.*

   After collision, cart A *has a speed of 4 meters per second. What will be the speed of cart* B *after the collision?*

ON YOUR OWN

Causing collisions

Battery-charged model cars which run on a track can be used to observe the effects of speed and mass in collisions.

You can set up different kinds of collisions. For example, you can pick two cars that have the same mass. (If you don't have an equal-arm balance handy, how could you get an idea whether or not the cars have the same mass?) Then vary the speeds with which the cars bump into each other.

You might also want to observe the effect when you change the mass of one of the cars. You will have to figure out a way to do that.

By the way, is there any difference between collisions that take place on the straight part of the track and those that take place on a curve?

If model cars aren't handy, try the same experiments with various small rolling objects that you can find. How are the speeds of any two moving objects affected if they do not bump into each other on a straight path but at an angle?

Chapter 10: Using Force

10

Suppose you're on a bicycle on a nice smooth stretch of road. There isn't a moving car in sight. The road is clear. The next crossing is a good distance off.

You start to pedal the bicycle as hard as you can. You're bent forward. Air is streaming past. It's a great feeling.

You notice that you're pushing down on the pedals at a fast but steady rate. The longer you keep applying the same "push" to the pedals the faster you go.

Of course, you can't keep speeding up forever. But at least for a short while, the longer you keep giving the bicycle pedals the same push, the faster you go.

The name for a push or a pull is *force*. Force needs to be applied to a bicycle to start it moving or to change its speed when it's already moving.

Force must be applied to anything to change its motion. Force and how it is related to motion is the subject of this chapter.

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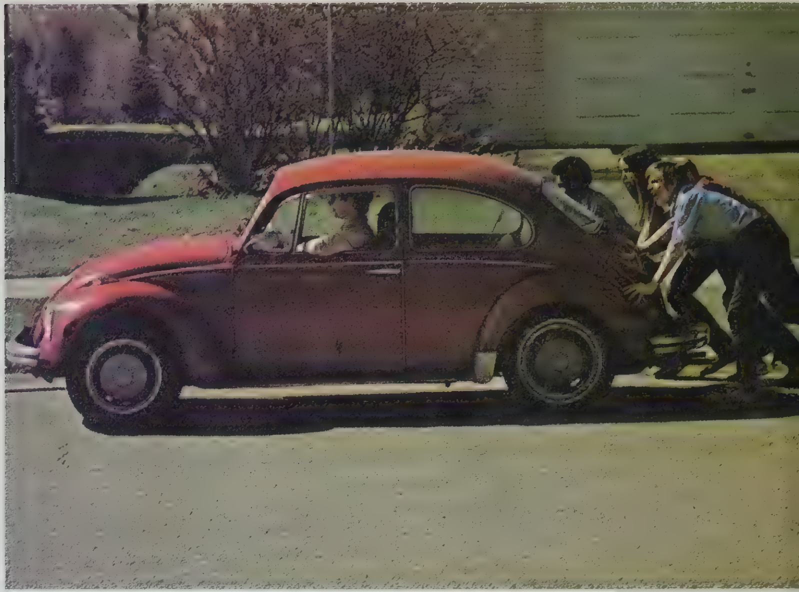
Pushing a car



10·1

Five people are standing around their stalled car. The driver, a teacher, has just remembered that the battery is very low. And there isn't a public telephone or service station anywhere in sight. Now they are going to be really late for their field trip.

Luckily, the car has a stick shift. The teacher tells the others that they need to get the car traveling only about 15 kilometers per hour. (The car is a foreign model with a metric speedometer still on it.) Then he can put it in gear and the engine will start to turn over.

Obviously the car needs a push or a pull to get it going. Its speed has to be changed from the value of zero. The driver gets behind the wheel. And the other four get ready to push the car. The one thing they feel thankful for is that the car is a small one. If it had a larger mass, it would be that much harder to push.

Another thing involved here, besides mass, is the change in speed required. The teacher tells them about a car he once had to push that had to get up to 25 kilometers per hour before it would start. After several sweaty minutes, that car was still not up to the necessary speed. "But don't worry," he quickly adds. "You'll get up to fifteen, no trouble." Still he hears someone grumble, "Sure, but I wish we needed to get to only 5 kilometers per hour."

The teacher also assures the students that, if they stick with it, they will soon get the job done. Since everyone agrees that they should get going as soon as possible, they decide to try to do the job in a minute or less.

There is a formula which can be used to compute the force needed to get the car moving to a certain speed. All three observations of the students are involved.

(1) The more mass an object has, the greater must be the push, or force, you apply to change its speed. (2) The more you want to increase the speed of an object, the greater must be the force you apply to get the job done in a certain time. (3) But you can increase the speed of an object the same amount with *less* force—if you apply that force for a longer time.

Check the following formula. It shows how these statements are related mathematically.

$$\text{Force} = \frac{\left(\begin{matrix}\text{mass of object}\\ \text{being pushed or pulled}\end{matrix}\right) \times \left(\begin{matrix}\text{change in speed}\\ \text{of object}\end{matrix}\right)}{(\text{time interval object is pushed or pulled})}$$

$$\frac{15\ \cancel{\text{km}}}{1\ \cancel{\text{hr}}} \times \frac{1000\ \text{m}}{1\ \cancel{\text{km}}} \times \frac{1\ \cancel{\text{hr}}}{3600\ \text{sec}} = \frac{(15) \times (1000\ \text{m})}{(3600\ \text{sec})} = \frac{15\cancel{00}\ \text{m}}{36\cancel{00}\ \text{sec}} = 4.2\ \frac{\text{m}}{\text{sec}} = 4.2\ \text{m/sec}$$

10·2 This calculation shows how kilometers per hour can be changed to meters per second. The units of measure are cancelled and multiplied just as factors in a fraction multiplication problem.

Now back to the stalled car. The teacher turns on the ignition. He is ready to start the engine when the car gets to the right speed. The other four get behind the car and begin to push.

Suppose they are in a scientific frame of mind and count off seconds as they push. For this experiment they should also be giving exactly the same size push the whole time. As the car hits 15 kilometers per hour, they have counted off 30 seconds. With a lurch, the car moves on its own.

We can use the mathematical expression for force to get an idea of how much force the four students were using.

From the measurements we have, we will get the general idea of how force, mass, and time are related in situations such as this. To be completely accurate, we would need to have more careful measurements. Some other things we would need to take into account would be the rubbing of the car tires against the pavement and any rough spots in it. Our calculations will give only approximate figures.

Since the expression for force depends on mass, we need to know the mass that was pushed. The driver's manual says that the car has a mass of 880 kilograms unloaded. And the teacher knows he has a mass of 70 kilograms. So the total mass of the driver and his car is 950 kilograms (kg).

The final speed of the car was 15 kilometers (km) an hour, or 4.2 meters per second. (See figure 10·2.) Since the car had been standing still, its change in speed is 4.2 meters per second. And the time interval was 30 seconds. You now have all the factors you need to compute the force used:

$$\text{Force} = \frac{\text{mass} \times \text{change in speed}}{\text{time interval}}$$

$$= \frac{(950\ \text{kg}) \times (4.2\ \text{m/sec})}{(30\ \text{sec})}$$

$$= \frac{(3990\ \text{kg}\cdot\text{m/sec})}{(30\ \text{sec})}$$

$$= \frac{\frac{3990\ \text{kg}\cdot\text{m}}{\text{sec}}}{30\ \text{sec}}$$

$$= \frac{3990\ \text{kg}\cdot\text{m}}{\text{sec}} \times \frac{1}{30\ \text{sec}}$$

$$= \frac{3990\ \text{kg}\cdot\text{m}}{30\ \text{sec}^2}$$

$$= \frac{133\ \text{kg}\cdot\text{m}}{\text{sec}^2}$$

$$= 133\ \text{kg}\cdot\text{m/sec}^2$$

This result is read as "one hundred thirty-three kilogram meters per second squared." Check to see where each unit in the result came from in the initial values. For instance, the first "*second*" in "second^2" came from the speed, "4.2 meters per *second.*"

The name given to the unit of force in the metric system is the *newton*. One newton is the force that must be applied *each second* to a 1-kilogram mass to change its speed 1 meter per second. You can write this definition in a mathematical way:

$$1\ \text{newton} = \frac{(1\ \text{kg}) \times (1\ \text{m/sec})}{(1\ \text{sec})}$$

$$= 1\ \text{kg}\cdot\text{m/sec}^2$$

The four students had to push the car with a force of 133 kilogram-meters per second squared—or 133 newtons.

UNIVERSITY OF ALBERTA

Using a truck in place of muscles

10·3 The car has stalled again. The decision is to send it to the repair shop.

What would have happened if a tow truck had come to the rescue of the five people? The truck, with its powerful engine, can exert more force than four sets of muscles.

Suppose a truck hitched up the car and began to pull, and after only 10 seconds the car was at the necessary speed and could be started. We can calculate the force exerted by the truck just as we calculated the force used by the four students. The mass of the car and driver is still 950 kilograms. And the car still changed from zero speed to 4.2 meters per second.

$$\text{Force} = \frac{\text{mass} \times \text{change in speed}}{\text{time interval}}$$

$$= \frac{(950\ \text{kg}) \times (4.2\ \text{m/sec})}{(10\ \text{seconds})}$$

$$= \frac{3990\ \text{kg}\cdot\text{m/sec}}{(10\ \text{sec})}$$

$$= \frac{\dfrac{3990\ \text{kg}\cdot\text{m}}{\text{sec}}}{10\ \text{sec}}$$

$$= \frac{3990\ \text{kg}\cdot\text{m}}{\text{sec}} \times \frac{1}{10\ \text{sec}}$$

$$= \frac{3990\ \text{kg}\cdot\text{m}}{10\ \text{sec}^2}$$

$$= \frac{399\ \text{kg}\cdot\text{m}}{\text{sec}^2}$$

$$= 399\ \text{kg}\cdot\text{m/sec}^2$$

$$= 399\ \text{newtons}$$

The four students used 133 newtons to get the car going. The tow truck exerted three times as much force, and so it was able to do the job in one third the time.

The truck was, of course, also using its engine to exert a force to increase its *own* speed. If you knew the mass of the tow truck and its driver, you could use the expression for force to calculate the total force exerted by the engine.

TEST YOURSELF

1. *Describe force in terms of the effect it might have when it is applied to something.*
2. *What are the three factors that affect the amount of force needed in a situation?*
3. *What is the mathematical expression for calculating force from the three factors in question 2?*

ON YOUR OWN

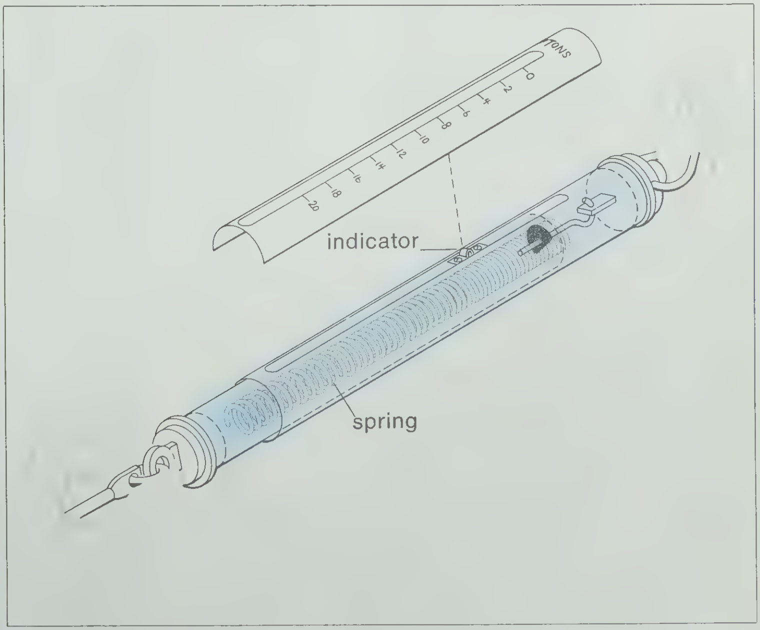
A stone on a string

Hang a heavy stone by a string from a fixed point. Tie another string around the stone. If you pull down on the lower string, which string do you think will break first?

Does it make a difference whether you pull down slowly or with a quick jerk? How can you explain this in terms of what you have learned about force?

Besides calculating force, you can find how much is being applied to something in another way. You can use a force measurer, which consists of a spring inside a narrow box with a scale on it. The spring stretches when force is applied to it. The amount it stretches is determined by the amount of the force (figure 10·5). So the scale is calibrated in newtons of force. When the spring is pulled by the hook, the narrow marker moves along the scale to the correct force value.

A force measurer for pushing or pulling cars would have to be specially made. But if the people trying to push the car (pages 254–55) had hooked such a special force measurer to the front end of the car and pulled on it as hard as they had pushed the car earlier, they could have gotten a force reading. The force measurer would have read 133 newtons during the 30 seconds the car's speed was changing from zero to 4.2 meters per second.



10·5 Newton spring scale (force measurer).

UNIVERSITY OF AL

You can use a more common force measurer to measure a pull or a push on a smaller object, such as a laboratory cart.

An interesting thing happens if the lab cart runs over the edge of the table. All of a sudden you are standing with a lab cart dangling at the end of the force measurer. At first, the cart might bob around on the spring. But when you steady it, you will notice that the spring is stretched inside the force measurer. The force measurer, in fact, could read about 12 newtons.

If you hang other objects on a force measurer, you will find that each object produces a reading on the scale of the force measurer. The reading is produced in each case by the attraction between the earth and the object, in other words, by the *weight* of the object.

When the lab cart causes a reading of 12 newtons on a force measurer, you can say that the lab cart *weighs* 12 newtons. A lighter cart might weigh 10 newtons, and a heavier one might weigh 30 newtons.

In scientific work, the mass of an object is always given in grams or kilograms. For example, whether you use an equal-arm balance here on earth or on the moon, an object will always have the same mass. However, its weight, measured in newtons, will change. Therefore, in scientific work weight is given in newtons in the metric system of measurement.

10·6a It takes 2.5 newtons of force to pull the cart along the table.

10·6b The pull of gravity on the cart (its weight) is 12 newtons.

TEST YOURSELF

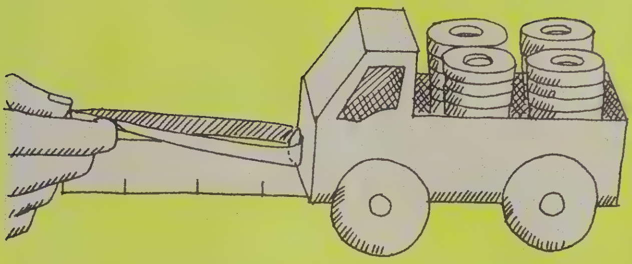
1. *In each of the following situations, indicate whether a force is acting, and, if so, what is exerting the force.*

   a) A car in a race is going from a speed of 160 kilometers per hour to a speed of 165 kilometers per hour on a straight stretch.
   b) A stone is falling off a bridge.
   c) A diver is plunging toward the water.

2. *A 5-kilogram mass is being pushed with a steady force. In 12 seconds its speed goes from 3 meters per second to 9 meters per second. What is the amount of the force?*

3. *A force measurer for pulling carts gives a reading of 3 newtons as the cart is pulled. When the cart is hung by the force measurer, it gives a reading of 25 newtons. What force is each of these two readings indicating?*

ON YOUR OWN



A truck in tow

For this experiment you will need to borrow a small child's toy truck. Or you can use a laboratory cart if you have one handy. You will also need at least one thick rubber band; a strip of lightweight cardboard about 10-cm long and 1-cm wide; and some small massive objects, such as nuts and bolts, to put into the truck to vary its mass.

Attach the rubber band to one end of the truck so that you can pull the truck by the rubber band.

Attach the cardboard strip next to the rubber band so that it extends out from the truck as shown in the picture. Now you're ready to experiment.

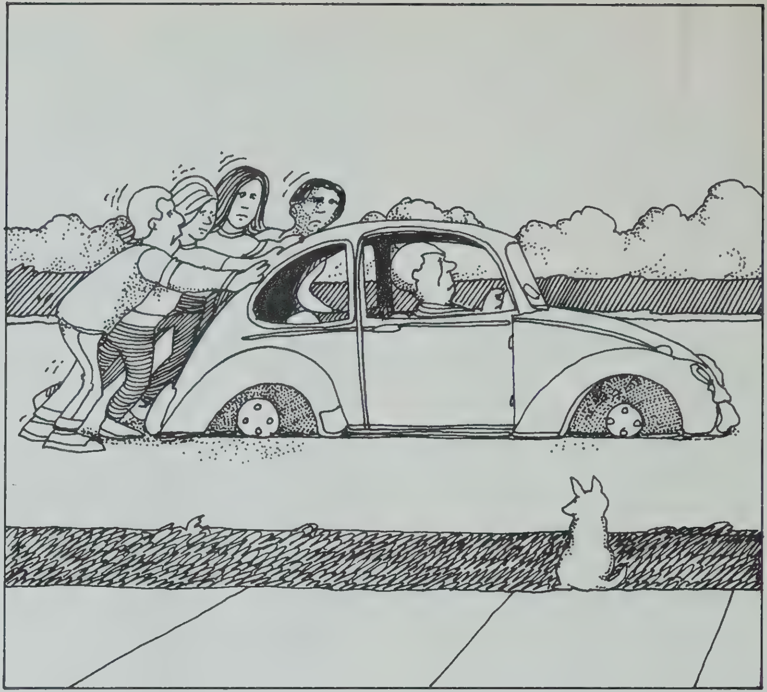
Pull the empty truck by the rubber band with a steady force through a distance of 3 or 4 meters on a flat surface. You can judge whether you're pulling on the truck with an unchanging force by keeping the rubber band extended the same amount the whole time you're pulling the truck by it. Put a mark on the cardboard strip at the distance to which the rubber band was extended as you pulled the empty cart.

As you kept pulling with the same force, what kept happening to the speed of the truck? Why?

Then vary the mass of the truck by putting in some nuts and bolts or some other small objects. Pull the truck over the same distance. Apply the same steady force each time by pulling with the rubber band extended the same distance each time.

Do you notice any difference in the way the speed changes as you vary the mass of the cart? Can you explain it in terms of what you've learned about the relationship of force, mass, and change in speed?

The force that rubs the wrong way



10·8

When the four students pushed the stalled car, we assumed that all their force went into rolling the car, slowly but steadily, up to the needed speed (pages 254–55).

But what if that car had not rolled? What if it had had no wheels and axles, but was just a car body resting on the ground? Would the job of pushing such a wreck have taken the same amount of force as rolling an equal mass on wheels?

The answer seems obvious. Of course the wreck without wheels and an uneven underside would be much harder to push along the ground. Extra force is needed to overcome what seems like an opposing force caused by the rubbing of the bottom of the car against the surface of the road.

This opposing force, caused by the rubbing of surfaces, is called *friction* force. In this case, friction between the car and the ground would require extra force to get the wheelless car to the same speed as the wheeled car in the same amount of time.

Just because the force of friction always hinders motion, that doesn't mean it is always a problem. For instance, think of the way you walk. You push off from your left foot to swing forward with your right, push off from your right to swing your left forward, and so on. If your back foot were always slipping and sliding, you couldn't get anywhere at all. But instead, when you push against your back foot, friction between your foot and the ground occurs. The result: your foot doesn't move until you pick it up.

Different surfaces cause different amounts of friction. If you are walking on ice, for instance, you have to adjust the push that you apply to your back foot when you take a step. Otherwise you will find out that the slippery ice doesn't give enough friction force. Your foot will go backwards, and you will fall down.

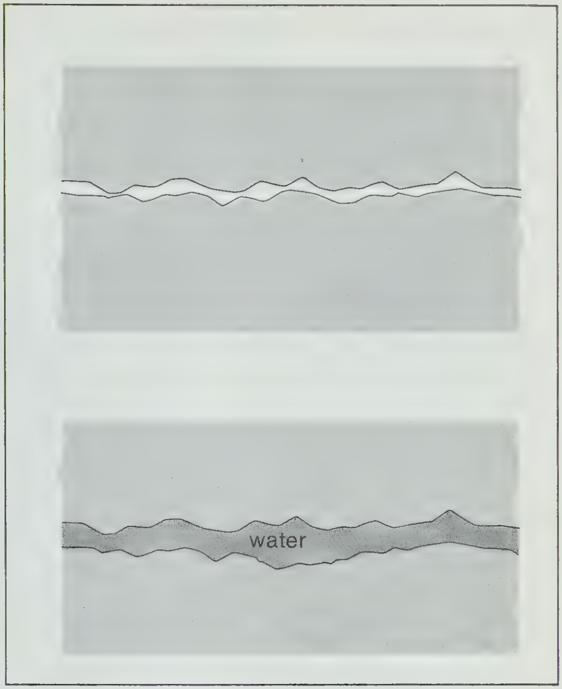
Why is it that ice or a wet sidewalk exerts so little friction force and a dry cement sidewalk exerts so much more? Here is one way to look at such friction:

Every surface has little high and low spots. Even surfaces that look perfectly smooth to the naked eye have some of these peaks and valleys. When two surfaces come in contact, their peaks and valleys overlap. It is the side of each "peak" pressing against the side of another "peak" that causes the resistance.

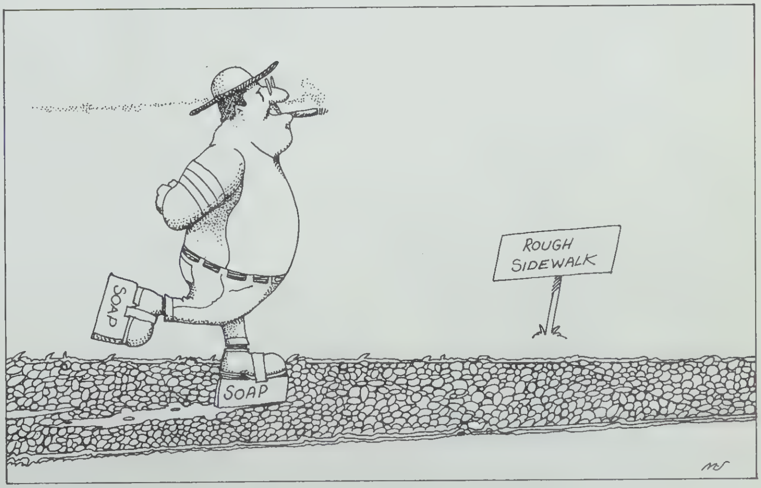
10·9

Naturally, a rougher surface, with higher peaks and more of them, will cause more resistance. So the rough concrete surface of a dry sidewalk is easier to walk on without slipping than a wet one.

Friction opposes the applied force on an object, and so affects the motion of any object. For this reason it is important to take friction into account when you do experiments with motion. Some of the force applied to change the speed of an object will be used up to overcome friction between any rubbing surfaces.



10·10 The high points on the rough surface catch each other as they are in contact. When a liquid fills in the low points, the contact between surfaces is smoother.



10·11

One way to cut down on friction between surfaces is to have them *roll* past each other instead of slide past each other. For example, a car with wheels is easier to push than one without wheels.

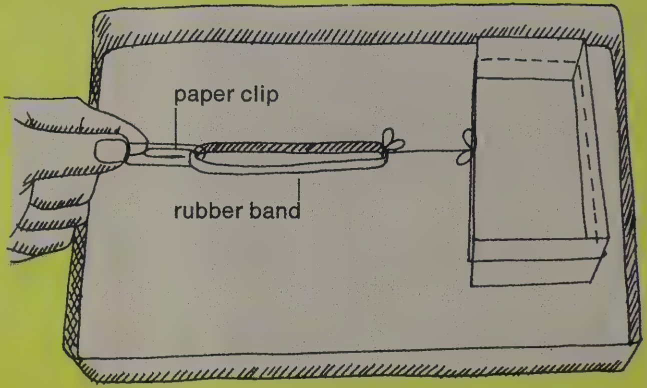
Another way to cut down on friction is to apply a lubricant, such as oil, to the surfaces that must meet. The oil causes a floating effect. One moving part slides past the other.

A very thin layer of water on a wet cement sidewalk produces the same floating effect, helping your feet slide from under you. You get a similar effect when you walk on ice. A little of the ice melts under your feet. That little amount of water will create a floating effect, making your feet slide.

TEST YOURSELF

1. *What is friction?*
2. *Give two examples where friction is useful.*
3. *Give two examples where friction is not useful.*
4. *How can friction be reduced between two surfaces rubbing against each other? Name two ways.*

ON YOUR OWN



Checking out some friction

You will need the following materials for this activity:

Small rectangular box
String
Rubber band
Paper clip
Flat board or a large tray

Tie one end of the string around the box. Leave a loose end of about 10 cm. Tie the rubber band to this end. Hook the paper clip onto the other end of the rubber band. Then drag the box across the flat surface by pulling on the clip.

The amount that the rubber band stretches indicates the relative force exerted on the box and the relative opposing force of friction between the box surface and the other surface. By the way, how could you measure the amount the rubber band stretches?

Try this experiment with the box sliding on its bottom, its side, and its end. Does the area of contact have an effect on friction force? Don't bet on your answer without trying it.

Next, moisten the flat surface on which you have been pulling the box. Repeat the experiment. Notice the amount the rubber band stretches this time. Is there a difference from the first experiment? If so, can you explain why?

Forces on the straight and narrow

Force changes the momentum of an object by changing its speed. Another way to look at force is as a push or a pull on an object. But what about the times you know you are pushing or pulling, but there is no speed at all?

There are many situations like that. One is tugging at the leash of a dog who insists on tugging in the opposite direction. Another is trying to push a stopped truck. No matter how hard you push, it doesn't move.

What is happening when a force doesn't seem to cause any change in speed? Look at the familiar example of a tug-of-war. The teams are pretty evenly matched. Suppose you are on the team at the right.

You can see and feel that your team is exerting a force to the right on the rope. But you can also see that there is no change in the motion of your team, the rope, or the other team. (Turn the page for figure 10·14.)

10·13

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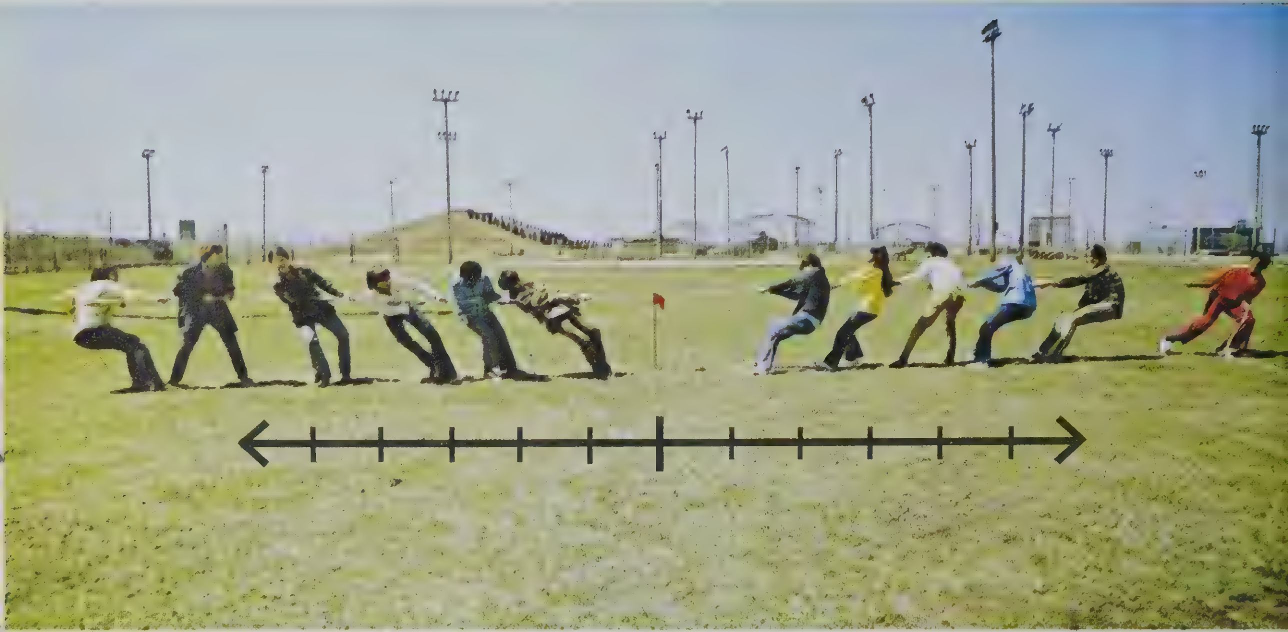
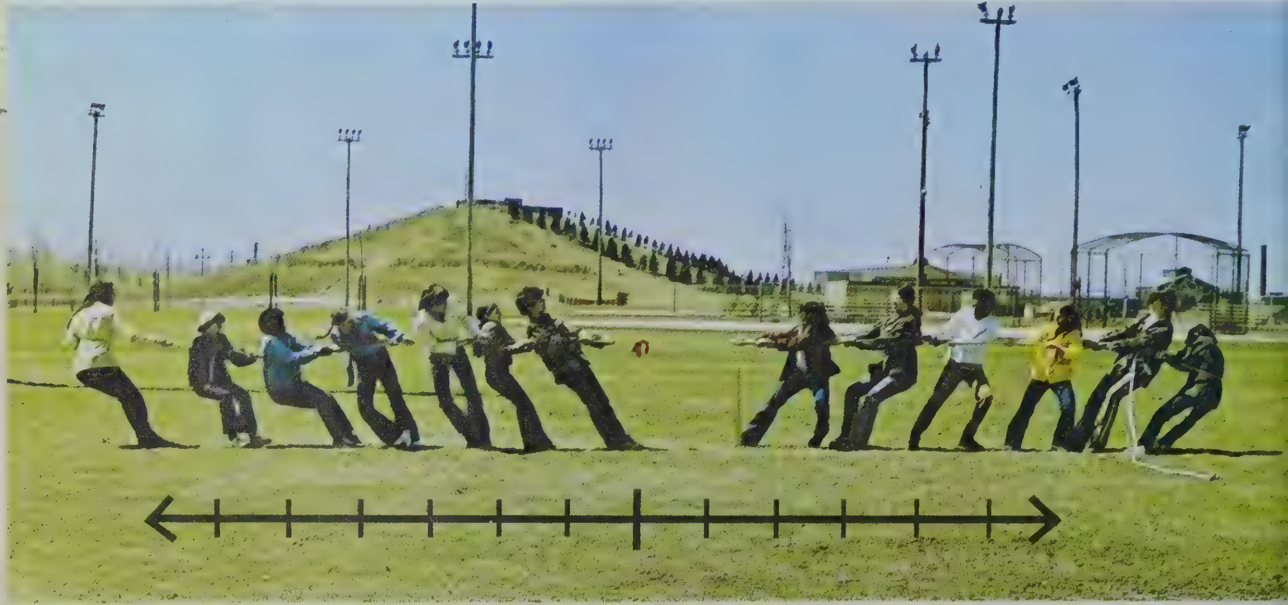


10·14 An evenly matched tug-of-war. Let's assume that each person on each team is exerting just about the same force, about 400 newtons. In the diagram on the photo, each section of the force arrows represents this 400 newtons. Since there are 6 people on each team, the total force each team is exerting is 2400 newtons.



10·15 An unevenly matched tug-of-war. Each section of the force arrows again represents 400 newtons. But this time the team on the left is exerting a force of 2800 newtons. There is an extra person on that team. The team on the right is still exerting 2400 newtons.

Now look at the tug-of-war from the point of view of the people on the other side. Their team is exerting a force to the left, and they, too, see no change of speed.

It looks as if the rules that govern force are suspended in this tug-of-war. But if you look at the big picture, you must take into account that two forces are being exerted on the rope at once: your team's and the other team's. They are equal in size, but opposite in direction. These forces are represented by arrows.

When the two force arrows are moved together, you can see the way they "cancel" each other out. It seems that equal forces on a straight line and in opposite directions create the same effect as no force at all.

You can put this information to use. For instance, if the rope is not moving, and you know the total force being exerted by the team on the left, you also know the total force being applied by the team on the right: It is equal to the force of the left-side team. When the center of the rope moves to the left, you can see that the left side has begun to exert a greater force than the right side.

Arrows can be used to represent the forces on any object. The length of the arrow can represent the amount of the force in newtons. The direction of the point of the arrow shows the direction of the force. You can use arrow drawings to help analyze combinations of forces acting on an object.

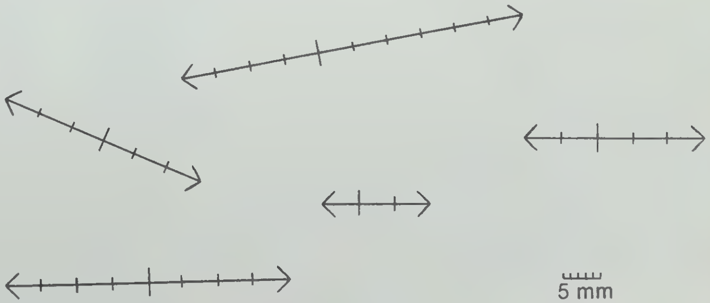
Which of the arrow diagrams in figure 10·16 represents the forces in an evenly matched tug-of-war?

In which situations in figure 10·16 are the two opposing forces *not* evenly matched? Which side is winning (applying more force)?

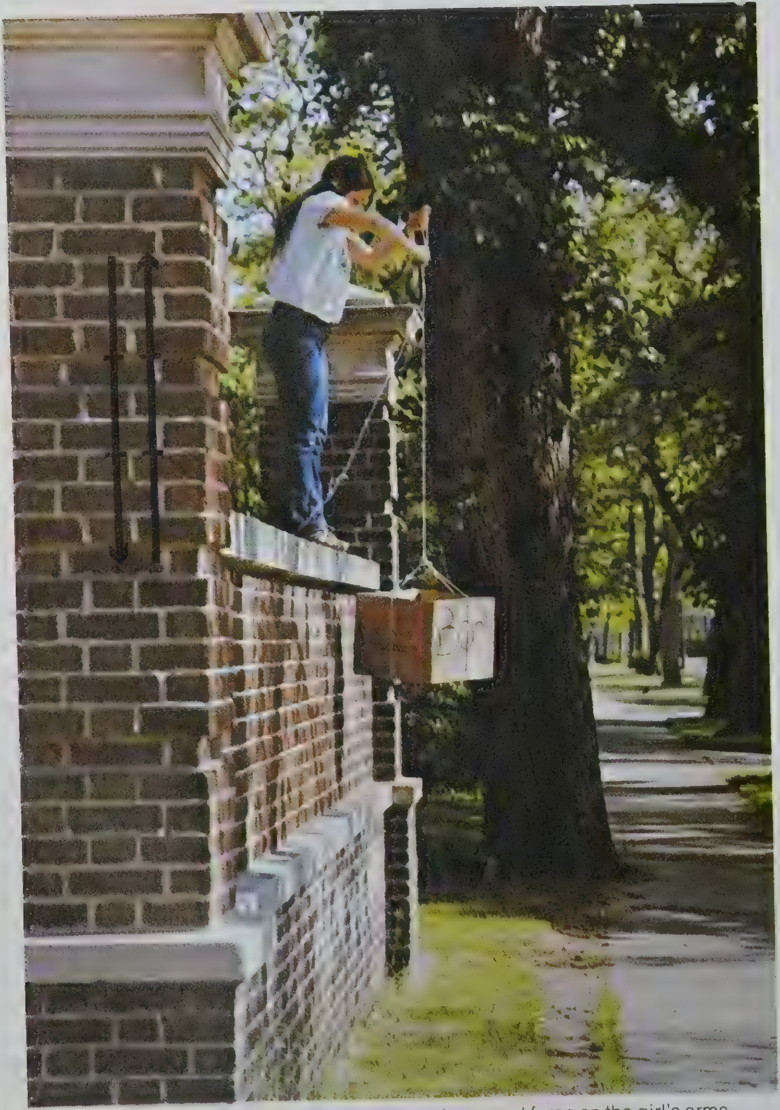
In these diagrams, one millimeter of arrow length represents 50 newtons of force. Therefore, a 5-millimeter-long arrow would represent a 250-newton force and a 10-millimeter arrow a 500-newton force.

You could use the arrows to find the amount of force that the losing side needs to match the winning side in each of the unmatched situations in figure 10·16. First, find the length of the arrow of the winning side. Then find the length of the arrow of the losing side. Then find the difference in length.

Subtract the length of the shorter arrow from that of the longer arrow. Multiply this difference by the scale, in this case, 50 newtons per millimeter. You will then have the extra amount of force that the losing side has to exert to catch up with the winning side.



10·16 Each 5 mm of arrow length represents 250 newtons of force.



10·17 The weight of the box of books exerts a downward force on the girl's arms. Her arms exert an upward force on the books. Both forces are equal. The box of books is not moving. Each section of the force arrows represents 40 newtons.

The person in figure 10·17 is having a different kind of tug-of-war. The pull of gravity on the box is one team. The girl is the other team. Gravity causes a downward pull on the rope, while the force exerted by the girl creates an upward pull on the rope.

TEST YOURSELF
Draw force arrows to represent each of the following situations:

1. *One team of a tug-of-war is exerting a force of 1500 newtons. The other team is exerting a force of 2000 newtons. Have your force arrows divided into equal sections. Have each section equal 500 newtons.*
2. *A man who weighs 900 newtons is attached by rope to a painting scaffold from which he has slipped. Represent the force on the scaffold and the rope's force on the man. Have each section of your force arrows equal 300 newtons.*
3. *A girl is standing on a spring scale. The scale shows a reading of 550 newtons. Represent the downward force on the scale. Have each section of your force arrow equal 50 newtons.*

Forces at an angle

Suppose a third, slightly larger team wants to challenge two tug-of-war teams. The two smaller teams decide to work together against the larger team. So three ropes are knotted at the center and each team pulls. The slightly larger team manages to balance both the smaller ones.

Notice though, that the smaller teams are at a small angle to each other. You can use force and direction arrows to find out the effect this angle has on the force these two teams actually exert against the larger one.

First, you need to draw an arrow to show the strength and direction of each team's force (figure 10·19). A scale is used to relate the length of arrow to the amount of force. The direction of the arrows can be indicated in degrees or according to compass points. The three arrows should all start at the point where the pulling force is being applied: the knot.

10·18

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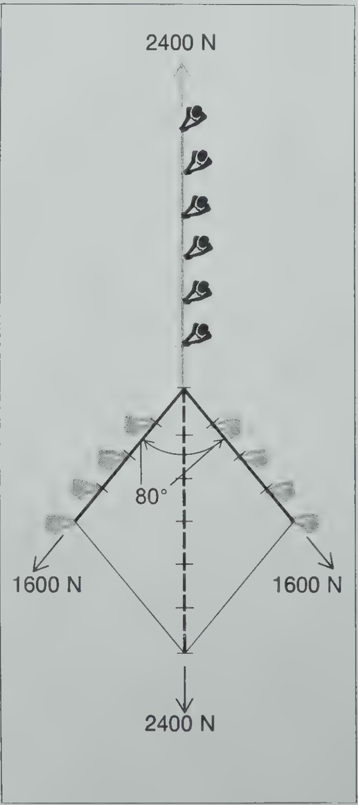
Taking the forces of the two smaller teams, you can next draw a parallelogram with the two shorter arrows as adjacent, or touching, sides. A parallelogram is a 4-sided figure with opposite sides parallel. But the inside corners need not be 90°.

If you draw a diagonal in the parallelogram as shown in figure 10·19, what is the size and direction of the force such a line could represent? What is the size and direction of the force exerted by the third, larger team?

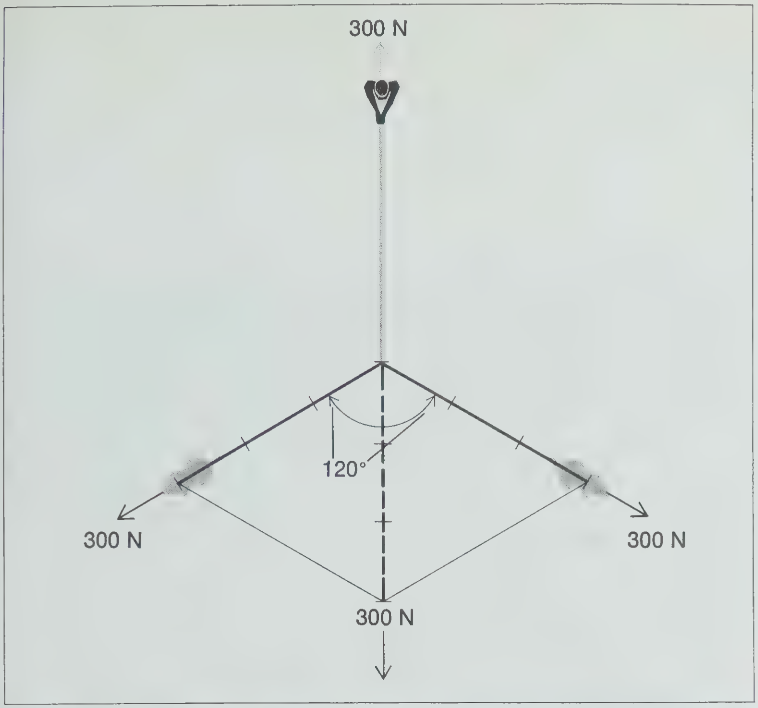
The force exerted by the two smaller teams together must be equal and in the opposite direction to the force of the third team, since these forces balance. (There is no motion.)

The diagonal in a parallelogram formed by two force arrows represents the combined force and resulting direction of two forces working together at an angle to each other. In this case, it's the combined force and resulting direction of the two smaller teams against the larger team. This method of diagraming forces working together but at an angle to each other is called the *parallelogram* method of force addition.

You can use arrow drawings and the parallelogram method in the same way to find where the boy in figure 10·21 is going. He works for a dog-walking service and is being pulled in two directions at the same time. If, on the scale of your diagram, each section represents 100 newtons, you can use the parallelogram method to add the forces of the two dogs and find the size and direction of the total force on the boy. He will have to pull backwards with that much force to avoid disaster.



10·19 A parallelogram of the three-way tug-of-war shown in figure 10·18. Each section of the force arrows represents 400 newtons. Each of the smaller teams is pulling with 1600 newtons in its own direction. However, the combined effect of the two smaller teams against the larger one is only 2400 newtons. This resulting force is shown by the dotted force arrow. In this case, the resulting force of the two smaller teams exactly balances the force exerted by the larger team. The force of the larger team is represented by the gray force arrow.



10·20 A parallelogram of the two dogs pulling against the boy in figure 10·21. Each section of the force arrows represents 100 newtons. Each dog is pulling with a force of 300 newtons in its own direction. But the combined effect of the two dogs against the boy is only 300 newtons. This resulting force is represented by the dotted force arrow. The boy will have to pull back with 300 newtons of force if he doesn't want to be pulled into the tree. This force is represented by the solid force arrow pointing away from the dogs.

10·21 Another three-way tug-of-war.

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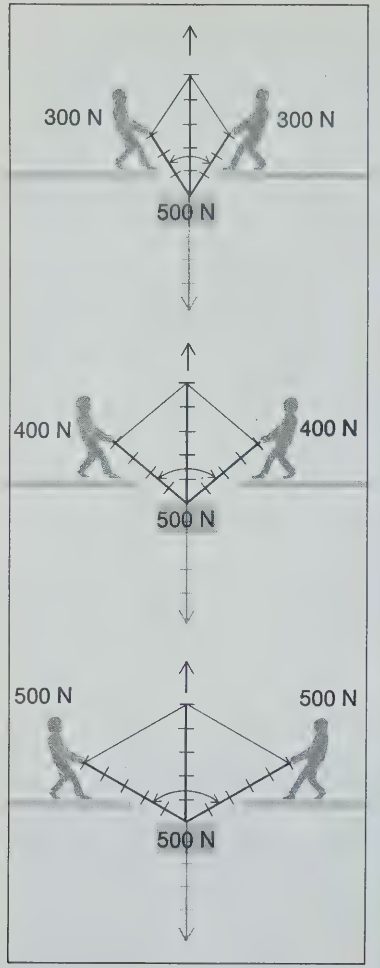
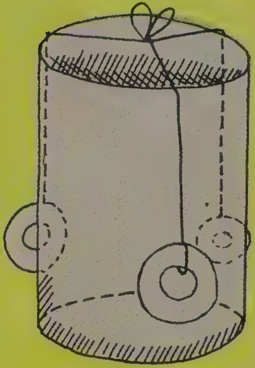


10·22

TEST YOURSELF

1. *For each of the situations in figure 10•22, what is the direction and amount of force resulting from the two smaller forces working against the third larger force?*
2. *Why does it take more muscular effort to lift yourself with your hands far apart on a chinning bar than with your arms straight up?*

ON YOUR OWN



A battle over a can of soup

For this experiment you will need a big can of soup, or a can of anything else; about 45 cm of smooth lightweight string; and some small massive objects such as nuts and bolts.

Cut and tie the string as shown in the picture. You will have three strands of equal length tied together in one spot. Attach different masses at the end of each strand. Then drape the whole thing over the top of the can. How do you have to spread out the strands so that the whole thing doesn't start sliding off the can?

The force of gravity is acting on each hanging mass. So what you have going on are opposing forces pulling on the top of the can.

Experiment a little farther. Increase or decrease the force exerted at the end of each string by changing the masses. How do you have to change the angle between the strands of the rope so that you keep the forces in balance?

Chapter 11: Doing Work

11

On docks by the ocean or by a major lake or river, you'll often see a lot of "work" going on. Workers use big cranes to load and unload the ships. In addition to strong steel beams, the cranes have pulleys and ropes, and motors to drive them. For lighter loads, the workers will sometimes use ropes and pulleys, but operate these with their own muscles.

Dockworkers also use the gangplank of the ships to raise things gradually up to the deck. And the crowbar the inspectors use to open crates also helps with work.

At one time or another, you have probably used devices like these to get some kind of work done. This chapter is about a specific kind of "work" and the way things such as pulleys, gangplanks, and crowbars make it easier.

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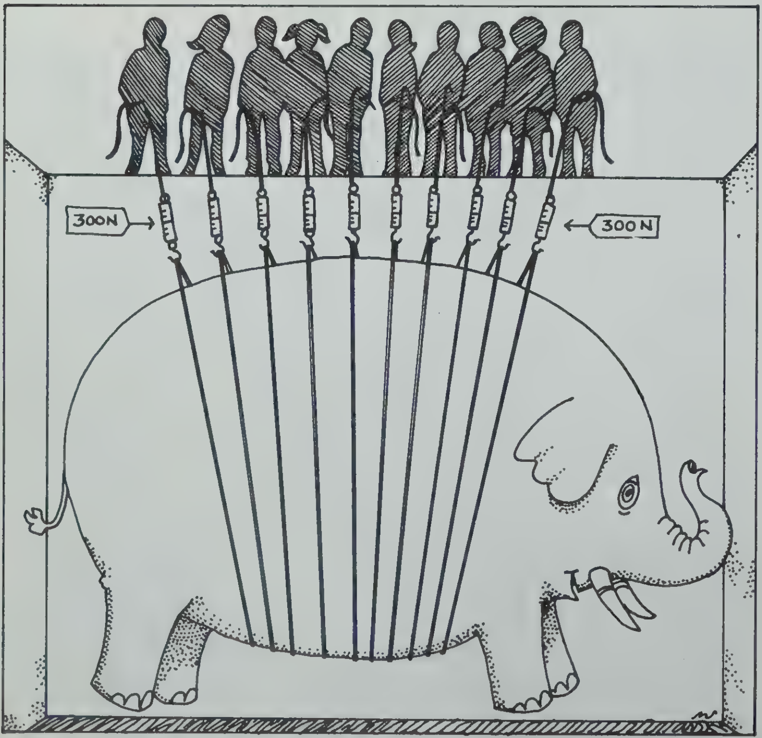
How to lift a small elephant single-handedly

On a trip to the docks, suppose you and some friends happen to see workers unloading a shipment of zoo animals. The workers are using a crane for the huge cages. Then suddenly the crane motor breaks down. Since it's lunchtime anyway, the workers leave. However, a baby elephant still on the deck of the ship needs to be lifted to the truck that will carry it away.

Before you start deciding with which hand to lift the elephant, you need to take a good look at the elephant. It is an ordinary baby elephant, weighing in at only 3000 newtons. As elephants go, it's a real runt. But to lift it is another matter.

You could get nine friends to help. Then there would be ten of you to share the load. And each of you would have to lift only 300 newtons.



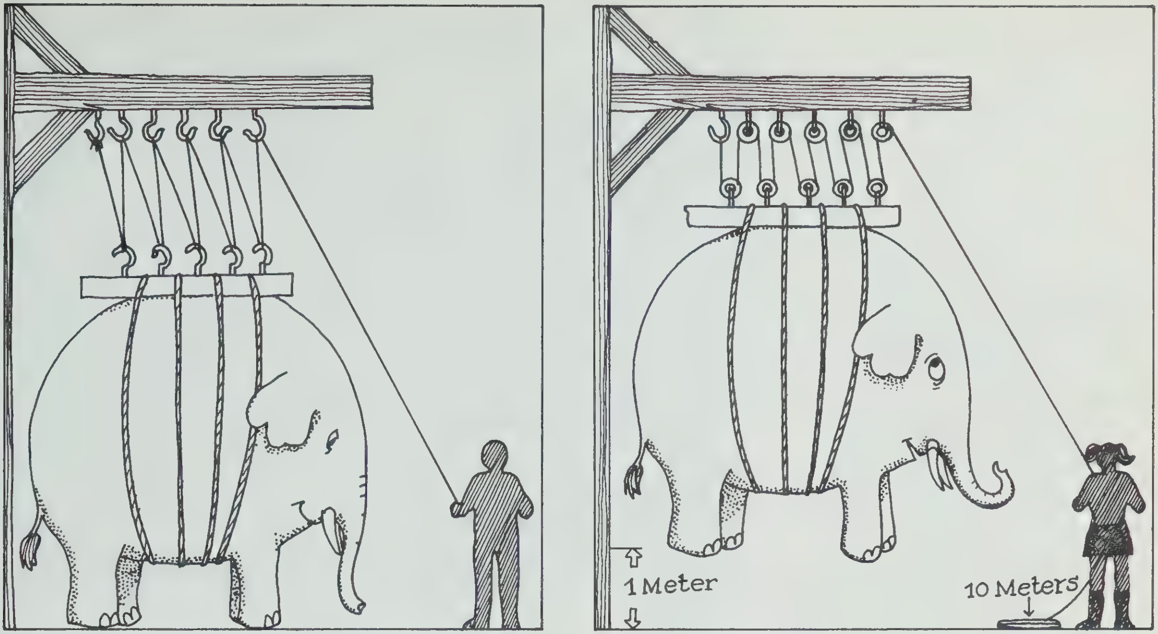
11·1

You could see this more clearly if each of you held the elephant by ropes to which force-measuring devices are attached. Each measuring device would read 300 newtons. And if there were twenty of you to lift the elephant, it would be even easier—if you could find enough room to stand around the elephant.

Having your friends help is only one way to share the load and lift the elephant. There is another way to do it. What you need is some way to hold up the elephant with some other kind of support.

You saw that you could support the elephant by hanging it from ten ropes. Why not run just *one* long rope from a hook on an overhead beam to the elephant, to beam, to elephant, and so on, through six beam supports and five hooks on the elephant?

Then by pulling the end of the rope, you will be pulling the rope up at each of the five hooks on the elephant. The six hooks on the beam will only give support and change the direction of the pull.



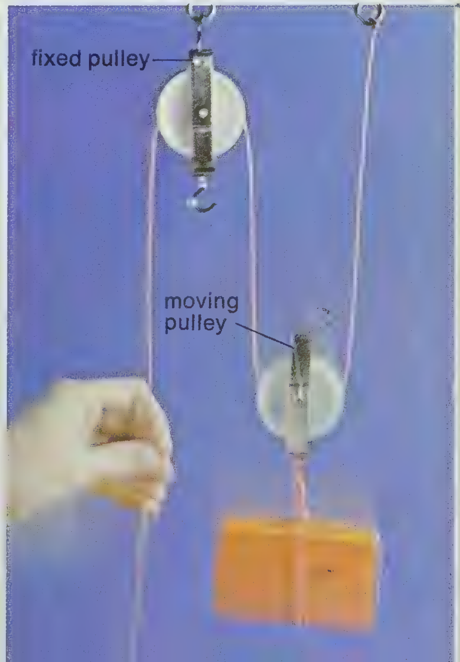
11·2

There will be a great deal of friction as you pull on the rope and it rubs against the hooks. The only place where this doesn't happen is at the first hook. At that one the rope doesn't slide through since it's tied down. Here you don't have to cut down on the friction. But you do have to cut down on it at all the other contact points.

An easy way to do that is to substitute a wheel for each of the hooks through which the rope is pulled. A wheel used to guide a rope in this way is called a *pulley.*

Most pulleys are built to be used in either of two ways—as *moving* or as *fixed pulleys.* In this case, the pulleys on the elephant are used as moving pulleys. They are given this name because they are lifted as the object is lifted. The pulleys attached to the beam are used as fixed pulleys. They do not move up or down with the object.

As you pull on the rope by yourself, the whole rope receives your force. Since the rope is free to move through all the pulleys, it exerts your force evenly, all along its length. Each uplifting rope applies your force to a moving pulley on the elephant. In this way the force you apply is multiplied by the number of uplifting ropes, 10 in this case. If you exert a force of



11·3 The pulley attached to the beam is a *fixed pulley.* The pulley attached to the box is a *moving pulley.* There are two uplifting ropes in this photo.

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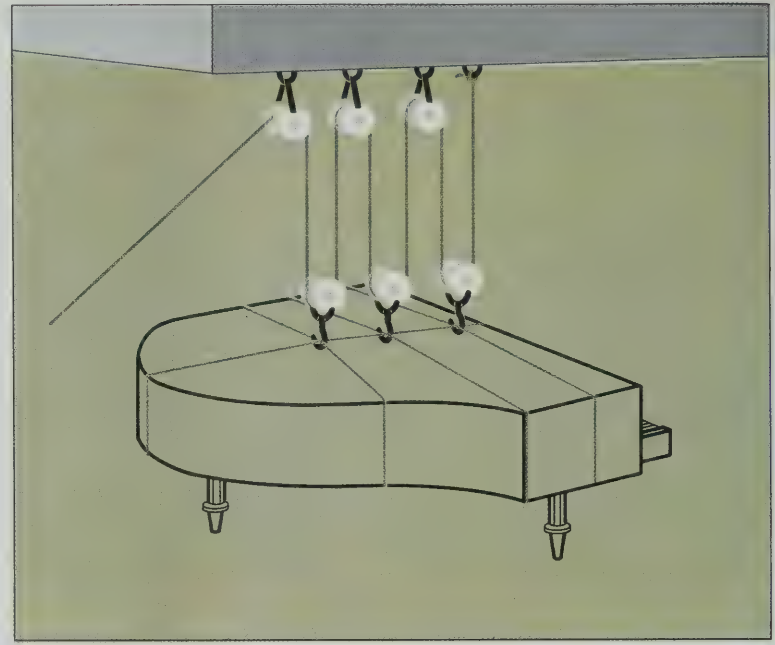
300 newtons, your force, applied by each of the 10 uplifting ropes, will exert a total force of 3000 newtons on the elephant.

At the same time, the length of rope that you pull comes equally from each of the uplifting rope sections. The end of each uplifting rope on the little elephant is raised the same amount. So the distance you pull out on the rope is divided equally among the ten uplifting ropes as they go up.

If you pull 10 meters of rope at your end, the moving-pulley end of each uplifting rope will rise 1 meter. And the elephant will rise with them—1 meter.

You pull 10 meters of rope to lift the elephant 1 meter off the ground. But you apply only 300 newtons of force to lift the 3000-newton elephant. So the force you use is effectively multiplied ten times. But the distance the elephant moves is only 1/10 of the distance you pulled on the rope at your end.



11·4

An important point should be mentioned here. If you were to do this experiment or a similar one, you would find that your results would not come out in nice round figures. Some of the force you apply to your end of the rope will be lost to overcoming friction. In this case of lifting the elephant with all these pulleys at what points do you think friction would be interfering?

TEST YOURSELF

1. *Why was it easier to lift the small elephant when there were ten uplifting ropes as shown in figure 11·2b than if there were only one uplifting rope?*
2. *Examine the diagram in figure 11·4.*
   a) Which pulleys are moving pulleys and which are fixed pulleys?
   b) How many uplifting rope sections are there in this diagram?
3. *Do you think it would take more or less force to lift the object as shown in figure 11·4 if hooks were put in place of all the pulleys? Explain.*

What have you done?

Now you can let the elephant down while you think about what happened during this exercise.

The job at either end can be described as a force acting over a distance. The distance at your end is the distance you pulled on the rope. The distance at the other end is the distance the elephant is raised. The force at the elephant is its weight, 3000 newtons. Gravity is pulling down on the elephant with 3000 newtons of force. And you found that at your end, $\frac{1}{10}$ as much force, or 300 newtons (N), was needed to raise the elephant against the pull of gravity in this case.

One way of evaluating the job that is done at each of these places would be to multiply the amount of force applied times the distance over which it is applied. The job done by you would then be:

$$300\ \text{N} \times 10\ \text{m} = 3000\ \text{N}\cdot\text{m}$$

The job done on the elephant would be:

$$3000\ \text{N} \times 1\ \text{m} = 3000\ \text{N}\cdot\text{m}$$

This product of force times the distance through which the force acts is the scientific definition of *work*. The unit of work in the metric system is the *newton-meter*. That is what you get when you multiply newtons of force times meters of distance.

When you multiply force times distance for the elephant, and force times distance for your end of the rope, the results are the same. This observation shows that the work done at your end of the rope is equal to the work done on the load, in this case, the elephant.

Work in the scientific sense is special in that it is limited to *moving* objects. If you try to push a stalled car without budging it, you may think of it as a lot of work. But the force is not applied over a distance: it is applied only at the one point of the unmoving car. Trying to raise a window that is stuck and holding a heavy load of books are also examples of forces that do not do this kind of work.

11·5

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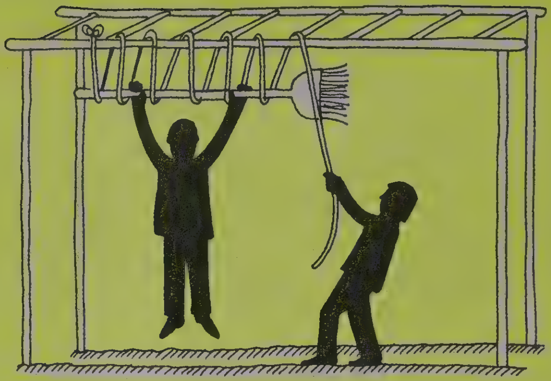
TEST YOURSELF

1. *What force are you overcoming when you lift an elephant, or when you lift anything else?*
2. *What is the scientific definition of the term "work"?*
3. *In which of the following cases is work being done?*
   a) A person is trying to move a piano. The piano won't budge.
   b) Another person is applying a great deal of force to a car which is moving very slowly.
   c) A child playing with a toy truck is pulling it with a string that is attached to the child's finger.
4. *If a 75-newton block must be raised to a height of 5 meters, how much work must be done on the block?*
5. *If you lift a 15-newton box 2 meters, how much work have you done?*

ON YOUR OWN



A broom as a person pulley

Tie one end of a rope to a strong horizontal bar and loop it back and forth around a horizontally held broom handle as shown. Have someone hold onto the broom handle. Try to lift that person by pulling on the free end of the rope.

Experiment with different numbers of supporting ropes. Is it easier to lift the person with fewer or more supporting ropes? Notice how the distance you have to pull on the rope varies with the number of supporting ropes.

If you're not getting the results you expected, could friction be interfering? If so, where? And how could you cut down on it?

Input versus output

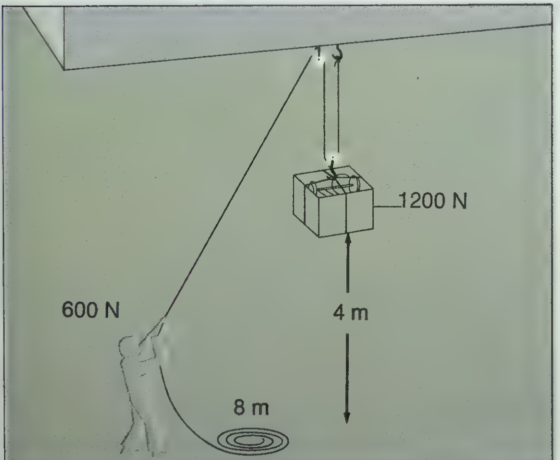
Suppose you wanted to lift a box of gym equipment weighing 1200 newtons to a height of 4 meters. You would have to do 4800 newton-meters of work to do the job. (1200 N × 4 m = 4800 N·m of work.)

You could use one moving pulley with two uplifting ropes on the load. Then consider the rule you learned with the help of the elephant. It tells you that you would need half as much force (600 newtons) and twice as much distance (8 meters of rope pulled) to do the job. (600 N × 8 m = 4800 N·m of work.)

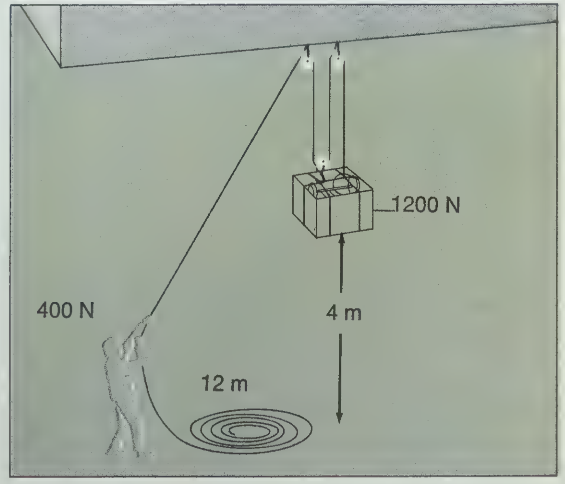
But what happens when you increase the number of uplifting rope sections to three? How is the force requirement changed? How is the distance you have to pull on the rope changed? Check the table below to find the force and distance requirements for the 4-, 6-, 12-, and 100-rope pulley systems.

Table 1

Number of uplifting rope sections	Force you apply to rope (newtons)	Rope to be pulled (meters)	Weight of load (newtons)	Distance load is lifted (meters)
2	600	8	1200	4
3	400	12	1200	4
4	300	16	1200	4
6	200	24	1200	4
12	100	48	1200	4
100	12	400	1200	4



11·7a



11·7b

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What answer do you get for each pulley-and-rope system when you multiply the force applied by the distance of rope that is to be pulled? For example, how does 400 newtons × 12 meters compare with 600 newtons × 8 meters? Note that this product of force times distance is the same for all the examples.

The amount of work that must be done at the free end of the pulley rope is the same for each pulley-and-rope system used. In other words, each pulley-and-rope system is to lift the same weight the same distance. This work done at the free end of the rope by you or someone else pulling on it is called the *work input.*

The amount of work that is done on the equipment box can be found in a similar way. Multiply the force acting on the box (its weight, 1200 newtons) by the distance through which the box moves (4 meters). The work done on the equipment box is the *work output*. In this case, it is 4800 newton-meters for each pulley-and-rope system.

Note that the *work input equals the work output*, no matter which pulley system is used. In a general way, this idea that work input equals work output holds true whenever force is applied to move something.

However, friction does interfere. In pulley systems there is friction between the rope and the pulley wheels. For the time being, let's think of the present cases as ideal ones. We'll get into the effects of friction a little later. But from what you already know about friction, how do you think it might affect the work output of these pulley systems?

By using the idea that work input just about equals the work output, you can design pulley systems to do work any way you want it done. You start out with an object of a certain weight to lift through a certain distance. If you want to pull with a force equal to only ¼ the weight of the load, divide the weight of the load by 4. To divide the weight with a pulley-and-rope system, you will need 4 uplifting ropes.

With the 4 uplifting ropes, you will have to pull 4 times farther on your end of the pulley rope than the load is to be raised. So multiply the distance you want to lift your load by 4 to find out what distance you will have to pull on the free end of the rope.

This relationship of work input, work output, and the number of supporting ropes in a pulley system can be stated mathematically. You can use the formula below for any situation in which you need to use a pulley system to lift a load.

$$\text{Number of supporting ropes} = \frac{\text{Weight of load}}{\text{force applied at free end}} = \frac{\text{Distance force applied at free end}}{\text{Distance weight raised}}$$

11·8 A pulley system on a construction crane.

11·9 Pulleys on a sailboat.

TEST YOURSELF

1. *A 2500-newton refrigerator-freezer is to be lifted by means of pulleys and ropes. There are 5 uplifting ropes in the system.*

   a) How much force must be used? (Assume no friction.)
   b) How much rope must be pulled to raise the box 4 meters off the ground?
   c) What is the work input?
   d) What is the work output?

2. *A weight is being lifted by means of a rope-and-pulley system. Three pulleys are attached to the weight, and three are attached to the ceiling.*

   a) Describe or draw the pulley system, including fixed and moving pulleys and the path of the rope.
   b) How many uplifting ropes are there in the system?
   c) If the weight of the object to be lifted is 1400 newtons, and the end of the rope is pulled 18 meters, what is the work output? (Assume no friction.)

3. *A person wants to hoist a 5000-newton generator by using a motor to pull on the rope. The motor can exert only 500 newtons of force.*

   a) Design a pulley-and-rope system to solve the person's problem.
   b) How many uplifting ropes does the system have?
   c) How many fixed pulleys?
   d) How many moving pulleys?

A machine can be very simple

There are other systems besides pulleys which aid in doing work. The idea behind these other systems is the same as for pulleys: They can help lift a load with a smaller force than would be necessary if the load were to be lifted by hand. But with all these systems, the smaller force must be applied through a longer distance to get this benefit. For example, if an object that weighs 600 newtons is to be raised 1 meter, you can use *less* than 600 newtons of input force if you can apply the input force over more than 1 meter.

The advantage is that these systems require less input force. But do they, in scientific terms, "save" any work? Or, in other words, would it be possible to raise a 600-newton weight 1 meter by using less than 600 newton meters of work?

The force-saving devices are called *simple machines.* A pulley is one kind of simple machine. The reduction in force in a pulley system depends on the number of uplifting ropes, which in turn depends on the number of pulleys.

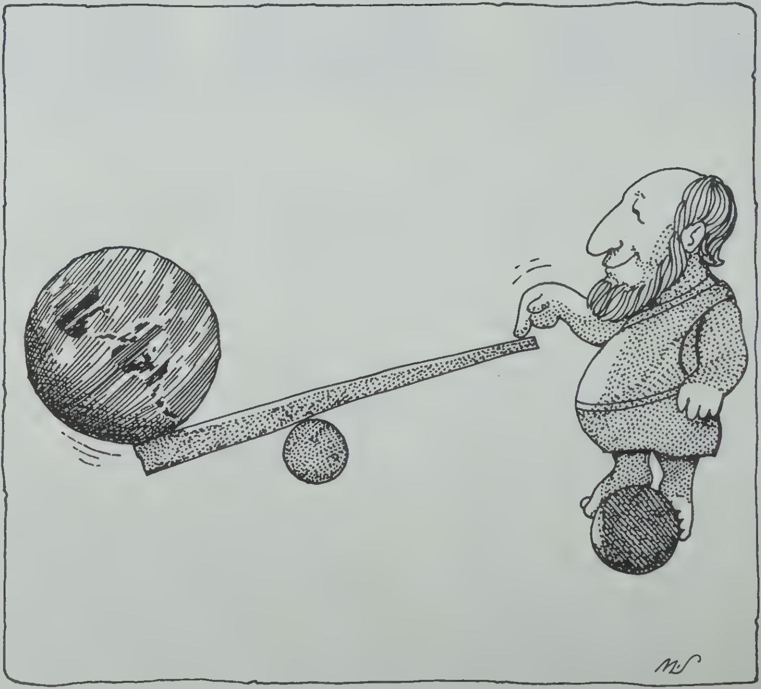
Other kinds of simple machines multiply the input force in different ways. You will see as you study them, though, that they share with the pulley the principle of lessening the input force.

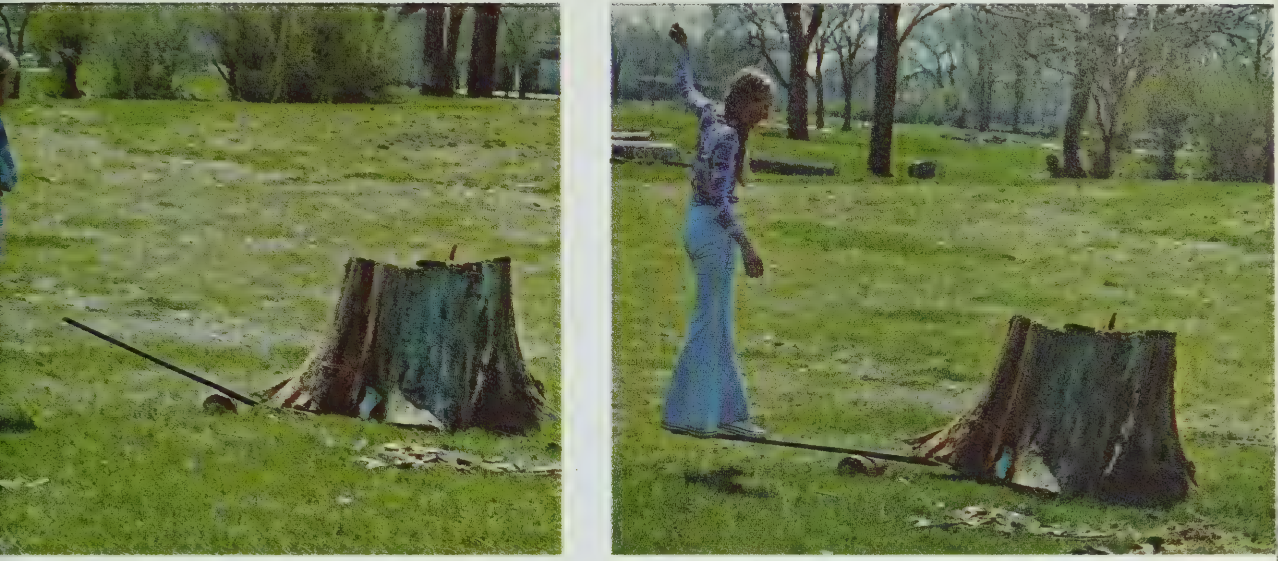
The lever, or "lifting the world"

The ancient Greek philosopher and inventor Archimedes is supposed to have said, "Give me a place to stand on, a lever long enough, and I will move the earth."

King Hiero, according to legend, commanded Archimedes to explain his boast. Archimedes did that. He placed one end of a long iron bar at the bow of a ship that was ready to be launched. Then he told King Hiero himself to

11·10





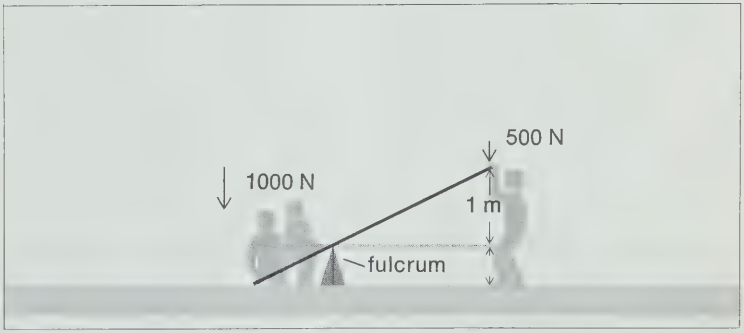
11·11 The girl cannot lift the tree stump without the lever.

Note how far the long arm of the lever goes down to barely lift the stump off the ground.

push lightly on the long end of the bar. As King Hiero did so, the other end of the bar caused the ship to slide into the water.

The name for a bar used in this way is a *lever*. A seesaw hinged off the center uses the same principles as the lever that Archimedes used. As an example, suppose a 3-meter seesaw board is placed on a pivot at a point 2 meters from one end and 1 meter from the other end. (This pivot point on a lever is called its *fulcrum*.) The long end, in this case, is twice as long as the short end. So the ratio of the long side to the short side is 2 to 1.

Notice the distance and the direction that the long end rises when the short end falls 0.5 meter (figure 11·12). How



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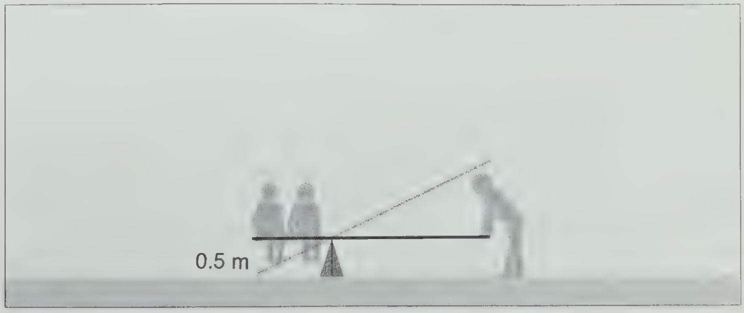

11·12b

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does the ratio of these distances moved compare to the ratio of the lengths of the sides?

Suppose two students whose combined weight is 1000 newtons are on the short end of the seesaw. The work output, in lifting them off the ground, is 1000 newtons × 0.5 meter = 500 newton meters (figure 11·12).

Once you know these figures for the work output, you can find out how much input force you needed to get these results. With this lever, the ratio is two to one. The two students were lifted 0.5 meter, so the long end had to go down twice that, or 1 meter.

The seesaw is a lever. The lever is a simple machine. And with simple machines work input will just about equal work output, if there aren't too many parts rubbing against each other causing friction. The seesaw board is touching its pivot at just one small spot, so friction isn't much of a problem here. So the work input = work output idea of the simple machine should hold true. Table 2 shows how this idea works on our 3-meter seesaw when the weight on the short end is changed.

Table 2
Lever Work Input = Work Output

Force applied to long end (newtons)	×	Distance through which long end moves (meters)	=	Weight lifted (newtons)	×	Distance weight is lifted (meters)
500 N	×	1 m	=	1000 N	×	0.5 m
?	×	1 m	=	800 N	×	0.5 m
?	×	1 m	=	600 N	×	0.5 m

By the way, you could have gotten these same results in the first example if, instead of pushing down on the long end of the seesaw yourself, you had put a 500-newton weight on that end.

TEST YOURSELF

1. *Describe or draw a diagram of a lever system. Include the location of the long arm, short arm, fulcrum, and load.*
2. *A 5-meter-long lever has a long arm of 3 meters and a short arm of 2 meters. A 60-newton weight is put at the tip of the short arm. What weight (in newtons) will have to be placed on the tip of the long arm to raise the 60-newton weight 2 meters?*
3. *A 4-meter-long lever has a 1-meter arm and a 3-meter arm. A 500-newton weight is at the end of the short arm. Another weight is put at the end of the long arm. That weight balances the 500-newton weight up through 0.5 meter. What will that weight have to be? Give it in newtons.*

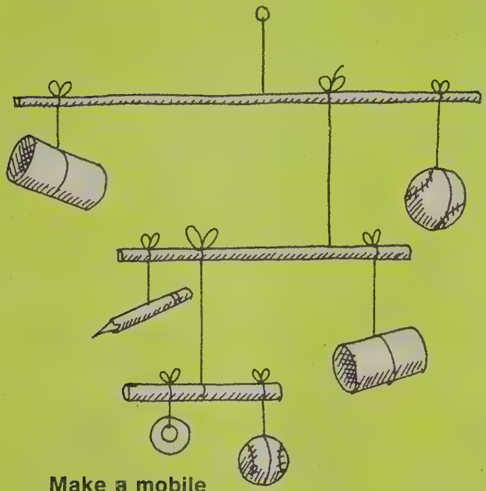
ON YOUR OWN

Meeting on a meter stick

Hold a meter stick horizontally on your two outstretched index fingers. Move your index fingers slowly toward each other keeping the meter stick level. Where on the meter stick do the fingers meet? Will they meet at another point if they are started at the 5-cm and 60-cm marks?

Where will they meet if different frictional materials are used instead of fingers, such as a large rubber eraser under one end and a metal rod under the other?

ON YOUR OWN



Make a mobile

A mobile is a combination of many levers. Make one using several sticks, strings, and common masses such as tin cans, baseballs, phonograph records —anything you want.

Attach each object to a string. Tie one object to each end of every stick. Then tie the sticks to each other in one of the combinations shown in the picture. Or make up your own combination. Then hang the whole mobile by one string.

All the sticks by which the different objects are hanging should be parallel to the ground.

Explain how each one of the horizontal sticks is working as a lever.

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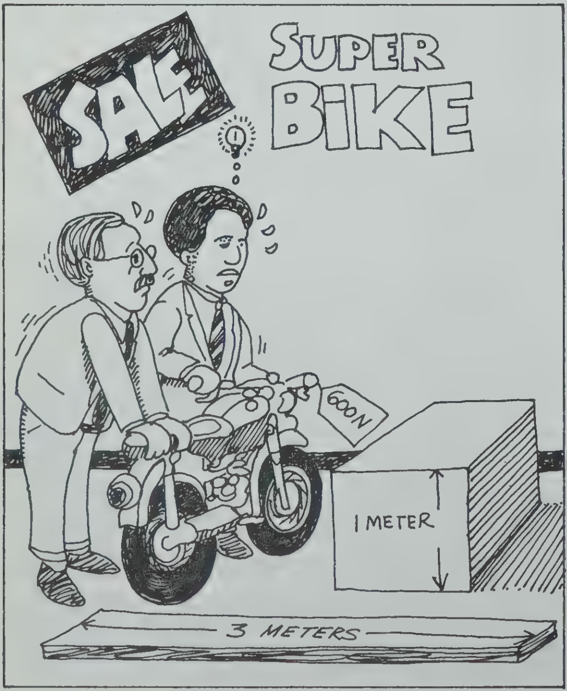
The manager of the two salespeople in figure 11·14 has told them to display a mini-bike on a meter-high platform. The weight of the bike is 600 newtons. They would rather not lift it straight up. A mechanical labor-saver would be handy.

They reason that, if a longer route to the platform can be used, they won't have to apply as much force to do the necessary work. Looking around, they spot a board left over from a carpentry project, and they decide to use that board as a ramp. A ramp used in this way is called an *inclined plane*.

To find the force the salespeople used, you must know how much work they had to do. It takes 600 newton-meters of work to lift a 600-newton mini-bike 1 meter straight up. If you roll it up a 3-meter inclined plane, the work is still 600 newton-meters. The input force used can be figured out as shown in Table 3. (Ignore the small amount of friction in the mini-bike wheels and between the ramp and the bike.)

How are these results similar to those you would get with a pulley or a lever?



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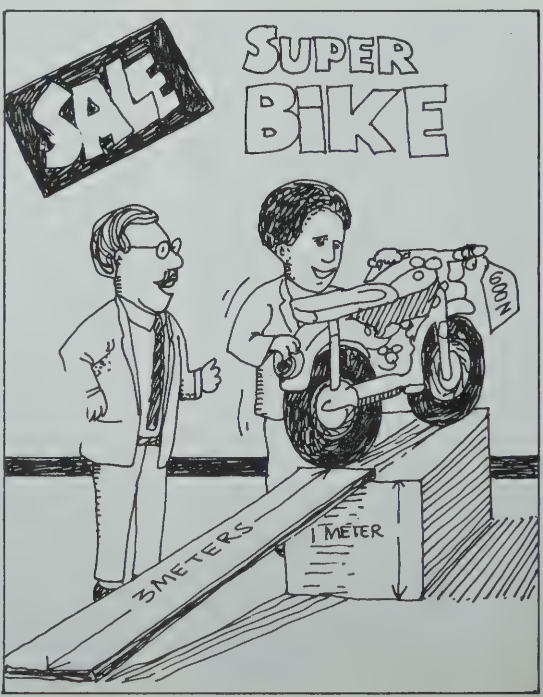

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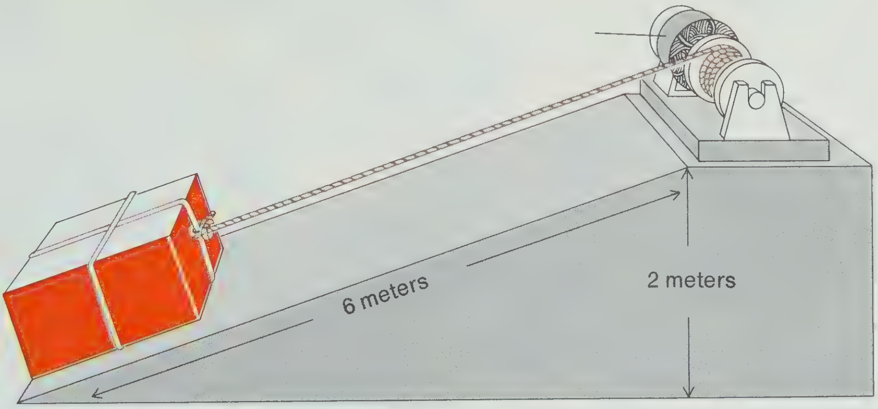

11·15

Table 3

Inclined Plane **Work Input = Work Output**

Force applied to push mini-bike up ramp (newtons)	×	Distance pushed (meters)	=	Weight of mini-bike (newtons)	×	Distance lifted (meters)
?	×	3 m	=	600 N	×	1 m
?	×	3 m	=	600 N·m		
200 N	×	3 m	=	600 N·m		

TEST YOURSELF

1. *What is an inclined plane?*
2. *Suppose you push a grocery cart weighing 200 newtons up a 3-meter ramp. The top of the ramp is 1 meter off the ground.*

   a) What is the work output in moving the cart 1 meter off the ground?
   b) What is your work input in pushing the cart up the ramp? (Ignore any effects of friction.)
   c) What force must you apply to push the cart up the ramp?
3. *The floor of a truck is 1.5 meters high. Workers are loading 250-newton cases of canned goods into the truck using a cart. If the workers use a 4.5-meter ramp up to the floor of the truck, how much force will they need to push 5 cases on a 100-newton cart?*
4. *A motor is being used to wind up a rope that pulls objects up a frictionless ramp to a height of 2 meters (see figure 11·15). If the length of the ramp is 6 meters, and the motor can pull with a force of 550 newtons, what is the maximum weight that can be hauled up the ramp with this motor?*

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The "Wake-Up" Machine

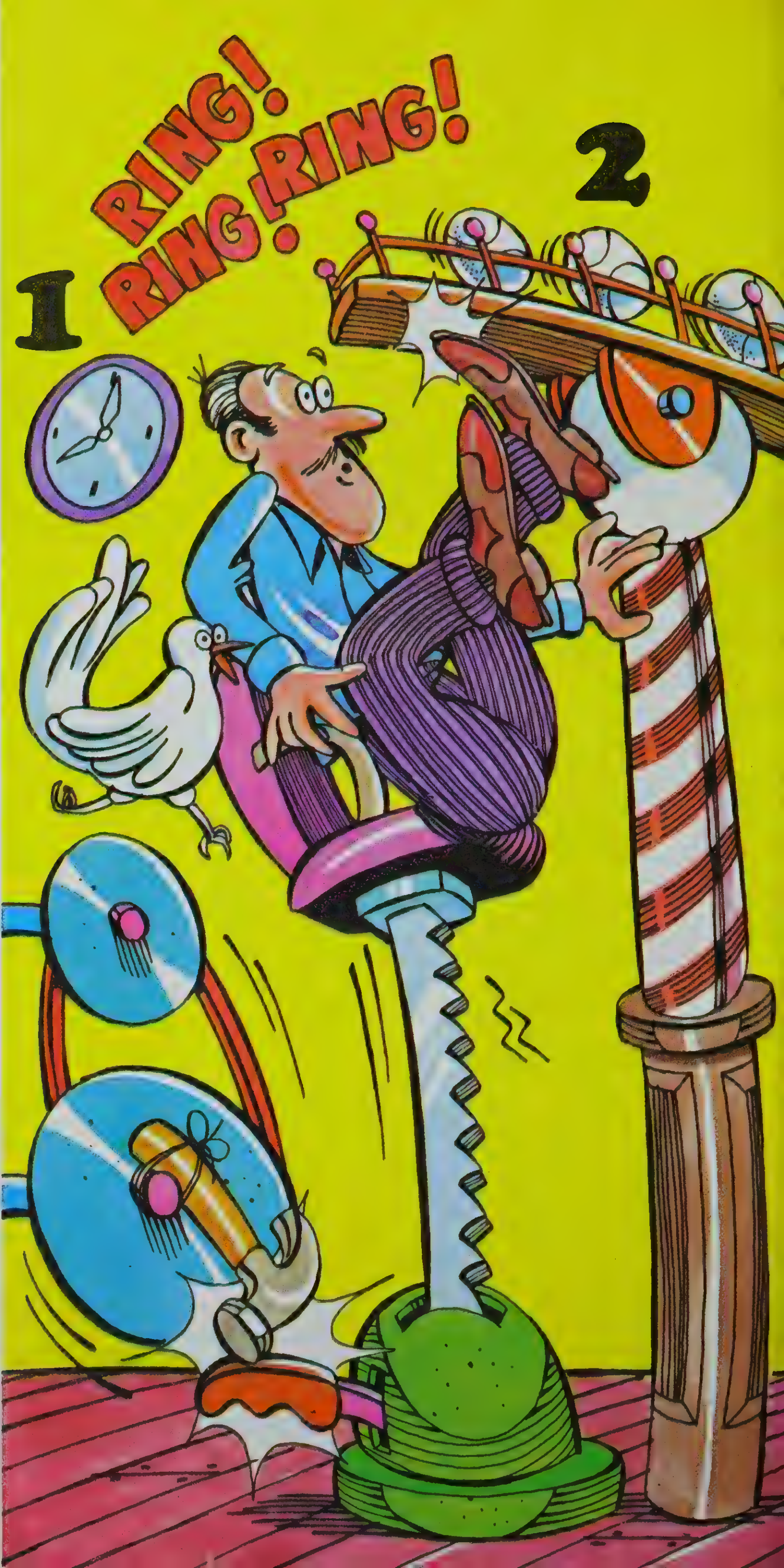
1. The alarm goes off. That's a cue to the bird. The result . . . the hammer hits the lever and the chair pops up.

2. The feet of the dozing inventor kick up, tilting the see-saw.

3. The baseballs roll off the see-saw, plop through a funnel, and hit a blue lever, which flips ping-pong balls from the pink bucket.

4. The baseballs bounce on the green lever, which makes the purple lever smack the ping-pong balls up the ramp.

5. The red pan tilts, the purple bucket tilts, and presto . . . the "wake-up" machine does its job!



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The advantage of simple machines

There is a definite advantage to rolling the mini-bike up the ramp. The people have to use much less force on the bike to do the required work. There is a similar advantage to using pulleys or levers to lift a load.

The force-reducing ability of a simple machine is called its *mechanical advantage*. This advantage can be found by dividing the force on the load (force output) by the force applied by whatever is moving the load (force input).

Consider, for example, the case of the elephant (page 273). Gravity was pulling on it with a force of 3000 newtons. But you could use a force of only 300 newtons on the rope to raise the elephant. Therefore the mechanical advantage of that pulley was 10 to 1:

$$\frac{\text{Force output}}{\text{Force input}} = \frac{3000\ \text{N}}{300\ \text{N}} = \frac{10}{1}$$

You can also find the mechanical advantage of a simple machine by dividing the distance through which the input force (your push or pull) is applied by the distance the load is lifted. For instance, the mini-bike was pushed 3 meters, but it was lifted off the ground only 1 meter. Therefore, the mechanical advantage of this ramp, or inclined plane, was 3 to 1:

$$\frac{\text{Distance input force is applied}}{\text{Distance weight is lifted}} = \frac{3\ \text{m}}{1\ \text{m}} = \frac{3}{1}$$

TEST YOURSELF

1. *What is the mechanical advantage of a pulley system which has 6 supporting ropes? With this system, you have to apply a force of 3 newtons to lift an 18-newton object 1 meter.*
2. *What is the mechanical advantage of a pulley system which has 5 supporting ropes? With such a system you could lift a 25-newton object with only a 5-newton force.*
3. *A board 4 meters long was lifted at one end to a height of 2 meters to form an inclined plane. What is the mechanical advantage of this system?*

Lost work

In all of the examples of simple machines, we did not take friction into account. But the pulley ropes rub on their wheels, the levers rub on their fulcrums, and the objects being pushed up ramps rub on the ramps. The result is a friction force that acts against the movement of the load. This force keeps part of the work input from actually working on moving the load. Only in an "ideal," friction-free situation can we say that the work input equals the work output.

In any ordinary real-life situation some of the work input is always used to overcome friction. To make up for this loss, you always have to put somewhat more work in than the machine puts out.

Often this work loss has a great effect on the way a machine does its job. By comparing the measured work output to the measured work input, you can determine the *efficiency* of any machine. Efficiency is calculated with this formula:

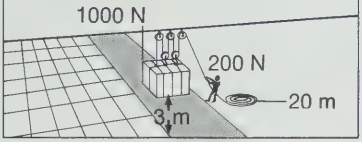
$$\text{Efficiency} = \frac{\text{actual work output}}{\text{actual work input}}$$

This formula can be used for simple machines such as pulleys, levers, and inclined planes (figure 11·17). Notice that the efficiency of each of the simple machines is given in a percentage.

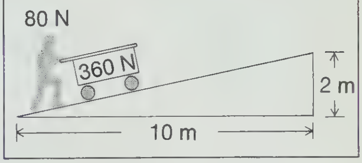
For example the pulley in the drawing has an efficiency of 75 percent. This means that only 75 percent of the work done at the free end of the rope was used to lift the box at the other end. The remaining 25 percent of the work input was used up overcoming friction. Study how the efficiency values were computed for the other example.

The formula for efficiency is also used by engineers who design complex machines, made up of a lot of simple ones. Even before a complex machine is built, the engineer can often estimate how much friction there will be. The types of material used and the points of contact between moving parts give the engineer an idea of how much loss to friction to expect. Once the complex machine is built, the engineer can use the formula for efficiency to calculate how well the machine works.

$$\textbf{Efficiency} = \frac{\textbf{actual work output}}{\textbf{actual work input}}$$
$$= \frac{1000\text{N} \times 3\text{m}}{200\text{N} \times 20\text{m}}$$
$$= \frac{3000\ \text{N}\cdot\text{m}}{4000\ \text{N}\cdot\text{m}}$$
$$= \frac{3}{4}$$
$$= 75\%$$



$$\textbf{Efficiency} = \frac{\textbf{actual work output}}{\textbf{actual work input}}$$
$$= \frac{360\text{N} \times 2\text{m}}{80\text{N} \times 10\text{m}}$$
$$= \frac{720\ \text{N}\cdot\text{m}}{800\ \text{N}\cdot\text{m}}$$
$$= \frac{9}{10}$$
$$= 90\%$$



11·17

TEST YOURSELF

1. *An 850-newton weight is lifted to a height of 2 meters with a pulley. The person pulling at the free end of the rope has to pull with a force of 200 newtons for 10 meters of rope.*

   a) What is the work output?
   b) What is the work input?
   c) What is the efficiency of the pulley?

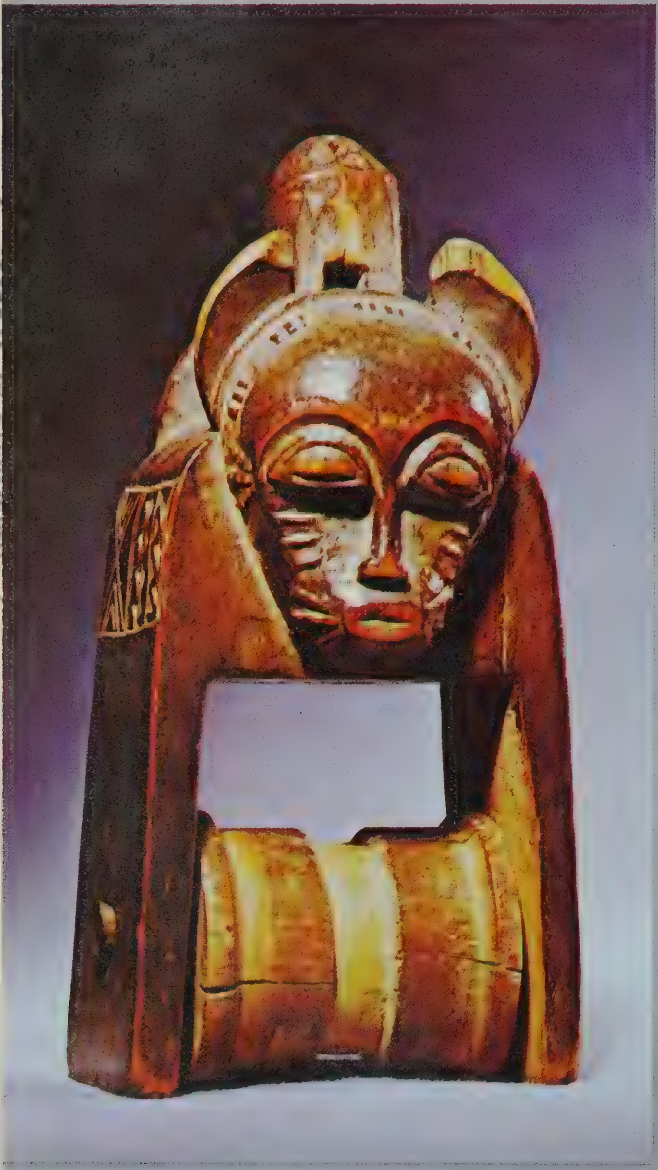
2. *An electric motor is used to haul packages up an inclined plane. The motor is rated for lifting a load of 500 newtons straight up. The top of the inclined plane is 2 meters high. The people using the setup have found that any package over 4000 newtons stalls the motor. The ramp itself is 18 meters long.*

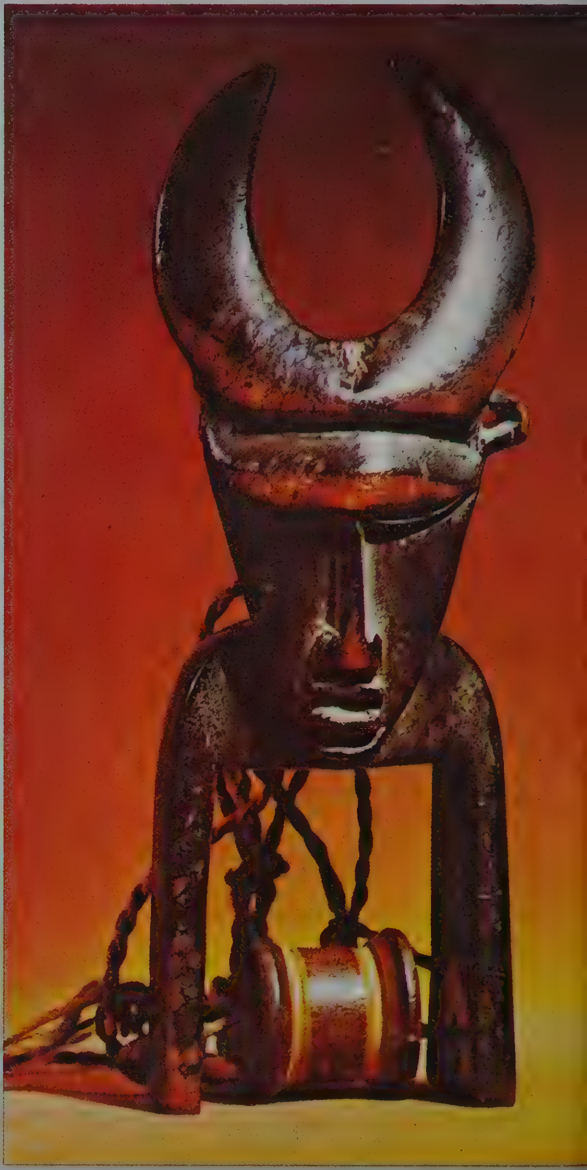
   a) This is not an ideal system due to friction. What is the efficiency of this inclined plane?
   b) How much of the actual work input was lost to friction?

3. *A motor with a 150 newton rating is used with a 10 meter inclined plane. A package weighing 600 newtons is placed on the inclined plane and lifted 2 meters.*

   What is the efficiency of this system?

African weaving loom pulleys. These small (10-cm to 20-cm high) useful pulleys are beautiful objects of art. Note the finely detailed sculpture.





ON YOUR OWN

Moving up an incline

For this experiment you can use the same child's toy truck or the laboratory cart you used in "A truck in tow" on page 259. Have the rubber band and the cardboard strip attached in the same way as shown on that page. You will also need a board a little wider than the truck and about 1 meter long.

Prop the board up so that it's at a slant. Then pull the truck up the whole length of the incline by the rubber band with an unchanging force, that is, by having the rubber extend the same amount the whole time you're pulling. On the cardboard strip, mark the distance to which the rubber was extended.

Then lift the truck, by the rubber band, straight up from the floor to the top of the slant. Does the rubber band extend a different amount this time? If so, why? Can you explain your observations in terms of work input and work output?

In other trials, you might want to change the slant of the board or the mass of the truck or both.

By the way, if you were to pull the truck up the incline on its side rather than on its wheels, how would the work input be affected? How would the efficiency of your simple machine, the incline, be affected?

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Simple machines in cranes, elevators, and escalators

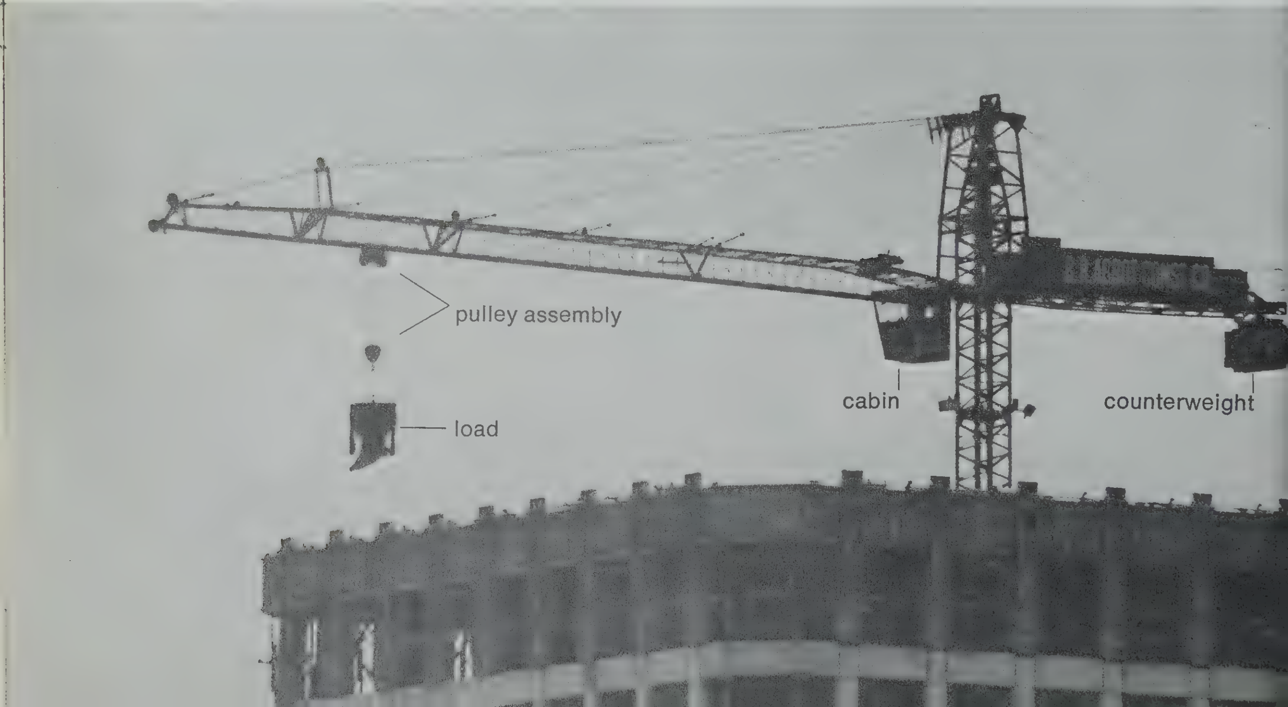
Up, Up, and Away

With all the rumbling, creaking, and clanking going on, it's hard not to notice a big construction project. Some complicated-looking machines are the cause of all the commotion. The huge cranes are the most obvious.

There is a lot of steel and cable used to lift girders, buckets of cement, or huge gulps of earth. Each rig looks far from simple. But a crane is just a collection of levers and pulleys, with an engine to supply the driving force. You may not recognize the fulcrum and arms of each lever easily. The two arms are sometimes separated by pulleys. This is done so that the crane can be used for different loads and movements.

Most cranes have a *counterweight* so that the lever arms can lift heavy loads. The counterweight balances a good part of the weight of the load to be lifted.

A tower crane is a common type of crane. It's often used on construction sites to place beams and other materials on upper



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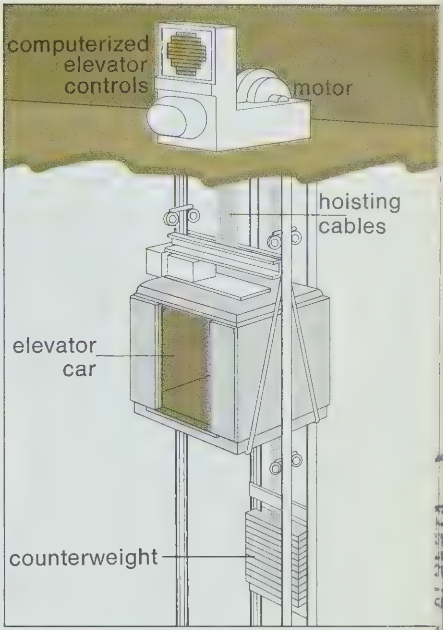


11·20b

floors. The counterweight is placed on the shorter lever arm and can be moved back-and-forth by means of pulleys. The longer arm of the lever is also connected by movable cables and pulleys.

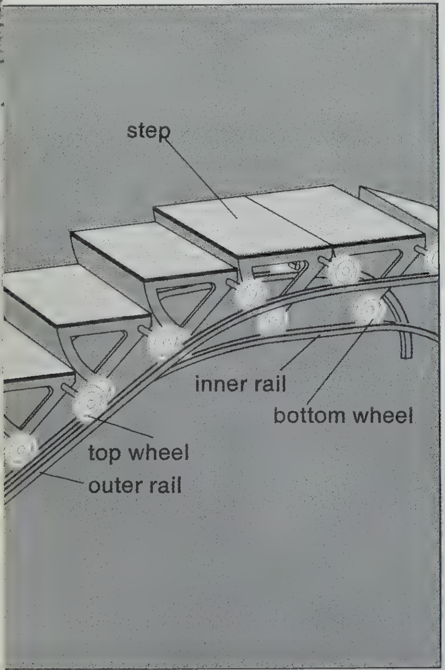
Lifting another kind of load

A machine you have probably often used also has pulleys. But you never see the pulleys in this machine. Except in the old cage-types with ropes and chains dangling everywhere, elevators usually keep their hard-working simple machines out of sight.

Modern elevators still use a refined pulley and counterweight system, as did the first ones back in the late 1800's. But now the pulley system is designed with exactly the right rope length so that the counterweight will reach the top just before the elevator reaches the ground. Similarly, the counterweight reaches the ground before the elevator can rise too high and damage the pulleys or the motor at the top of the shaft.

Springs and oil-filled buffers are used to cushion the counterweight and elevator. These are necessary in case something goes wrong with the pulleys or the counterweight. With modern electronic safety devices, though, it is almost impossible for an elevator to go for a crash-landing.

11·21a



11·21b

Sliding up

In the late 1800's, another form of getting upstairs also came on the scene. The escalator uses the principle of the inclined plane to move people continuously upward or downward. The incline on the original escalator was about 25 degrees.

The original escalator also used a continuous belt of stiff rubber steps that didn't flatten out at top or bottom. Another disadvantage was that the riders could not stand completely straight, but had to lean during the whole ride.

Later, the now-familiar steps were introduced. These move up at a 30-degree angle and are built so that the passengers can stand straight up. The steps are moved by a chain, driven by a motor. The steps ride on two sets of wheels which roll along two sets of tracks. During most of their length, the tracks run together. But at top and bottom, the tracks for the wheels on the thicker part of the step drop down. In this way, the steps form a platform so that the passengers can get off and on easily.

Another improvement was the comb plate at either end of the escalator. This addition made it easier and safer to get off and on. Still another safety feature is the cut-off switch. The escalator stops if anything is caught in it.

Escalators move at either 30 or 40 meters per minute. And they can handle 8000 people per hour at the slower speed! The running gear of escalators is designed to be ten times stronger than required. The result is that some escalators have been operating smoothly for 50 years. One reason is that escalators don't need the fancy electronics, floor selectors, and direction changes, as do elevators. Escalators are moving inclined planes: just simple machines.

Simple machines used in the building of ancient monuments

Heave ho!

How do you lift a $2\frac{1}{2}$-ton concrete block—without bulldozers, without huge cranes, without steam engines, or electrical motors? The ancient Egyptian pyramid builders did just that. The builders of another type of monument, Stonehenge, England, also lugged around stones which weren't much smaller.

A circle of stones

Stonehenge is a carefully laid out circle of huge upright stones with stone crosspieces. These are surrounded by banks, mounds, and circles of post holes. It stands in ruin now, due to nearly four thousand years of wear and tear. However, from a study of these ruins and the surrounding country, scientists have been able to piece together a story of how this huge structure may have been built.

The huge "blue stones" in the center of Stonehenge were originally transported about 210 kilometers by thousands of workers.

11·22 Stonehenge. This stone monument was built between 1800 and 1400 B.C. The newest theory suggests that Stonehenge may have been an accurate astronomical observatory. It might have been used for predicting eclipses of the sun and moon and the longest and shortest days of the year.

This material can be found only at that great distance, on the cliffs of Mount Prescelly in Wales.

The stones were carved by countless blows with smaller stones of the same material. Some of these stones that were used as hammers had a mass as great as 15 kilograms. Yet they made only a bit of dust each time a worker brought one crashing down on the cliff—the material is that hard.

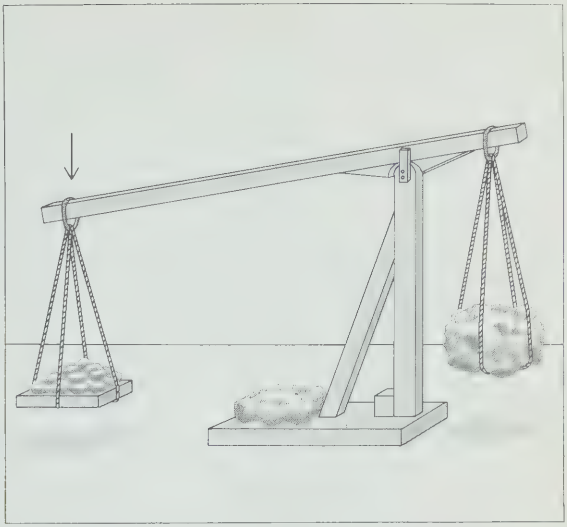
When the workers had finally cut the stones loose, they hauled or slid them down to the sea. Then they probably floated the stones to Stonehenge on sturdy rafts. Other gangs dragged the stones the rest of the way. The largest of these stones would have required fifteen hundred workers to get it started on the long path of log rollers that led to Stonehenge.

The stones used for the outer circle of Stonehenge were carved of a sandstone called sarsen. These were carried by the same process from their source 30 kilometers to the north of Stonehenge. We don't know much about the people who did all this hard work. There is only the archaeological evidence of their path.

Then comes the really big question: How were these huge stones placed in their precise positions, on the circle and within it? The people of Stonehenge apparently did it in teams. The hole for a stone was dug so that one wall slanted outward at about 45 degrees. The stone was pushed over roller logs down this incline. Then some 200 workers would haul the stone upright with fiber or leather ropes. Because the stone was so heavy, they had to fill in the slanted side of the hole in a hurry. So they used rocks, tools, leftover food—anything they could think of to plant the thing in its hole permanently. The evidence of this haste is the rubble found by digging around the stones.

Little is known about how the cross-laid stones were put in place. There are really no marks, records, rubble, or special tools around Stonehenge to suggest an answer. Wooden scaffolding might have been used to raise each end of a stone bit by bit. Workers might then have stood at the top of the resulting structure to do the final positioning. The work was then finished. But it's anyone's guess how long it took.

11·23 The Pyramid of Khufu has been the largest stone structure in the world for almost 5000 years.



11·24 Wooden machine used by present-day Egyptian workers to move stones. Similar machines, larger in size, may have been used to build the Pyramids.

Another kind of ancient skyscraper

The carved pictures and hieroglyphics written all over the Great Pyramid of Khufu in Eygpt—by workers and priests alike—are practically an open book. From studying the pyramid itself and the writings on its wall, archaeologists have pieced together how the Great Pyramid was probably built. Though not all scientists agree on all points, here's the story.

The stone used for the base of the pyramid was granite, which was quarried nearby. Farmers and other workers floated the stone down the Nile on rafts during the yearly flood time. The flooding of the farm lands left many farmers free to do this work. A canal carried the stone from the Nile to the plateau on which the pyramid was built. From the canal, workers probably hauled the stones on wooden rollers down a specially built path. The rollers were "leap-frogged" from behind the stone to form a path in front of it as it progressed.

White limestone for the outer layer of the pyramid came from southern Egypt. This stone was also brought down the Nile to the building site during flood time.

The Great Pyramid was built of about 3,000,000 granite blocks. These weigh an average of 2½ tons each. There is no picture or record of the Egyptians' using any kind of machine to move them. Most archaeologists have believed that a ramp was built up to each layer on the pyramid. The ramp was made higher but longer for each succeeding layer to keep the ramp at an easy slope.

The Greek historian Herodotus visited the pyramids about 450 B.C. He learned about the pyramids from priests who already thought of them as ancient. He heard tales of a machine built of "short wooden planks" supposedly used to lift the building blocks upward from layer to layer of the pyramid.

Studies of the pyramids have since shown that the priests often told Herodotus stories to amuse rather than to inform him. But this business of the machines could be important. The reason: modern engineers have calculated that there weren't enough workers in all Egypt to bring materials and to build a ramp of the size needed to place the topmost stone, no matter how determined the Pharaoh might have been. Remains of ramps have been found, but they couldn't have been used more than halfway up the 146-meter pyramid.

It was this engineering point of view that recently showed a person named Olaf Tellefsen a possible solution. He saw present-day Egyptian workers using a wooden machine to move huge stones. They were taking only ten minutes to move blocks weighing over a ton!

The device had a three-legged base about 2 meters tall. A 6-meter beam rested on the base. The beam was perched so that it had a short arm from which a sling dangled, and a long arm, from the end of which hung a small platform. Three workers cooperated to put the sling around the heavy stone. Then they piled rocks on the small platform. This end then acted as a counterweight. When the workers finally added their own weight to the platform, the stone block was raised about ⅓ meter off the ground. This distance was enough to slide log rollers under the stone block. With more workers, a larger machine could have been used to raise blocks the distance between levels of the Great Pyramid. It's an interesting possibility—a sort of primitive crane.

Chapter 12: What Goes Up, Must Come Down

12

The diver stands still at the top of the diving platform. She has done her work to get up the ladder. Then she begins her plunge downward.

A skier has just been hauled up a long slope by a tow bar. At the top of the ski run she pauses a moment, bends her knees slightly, and just leans forward to begin the long swoosh downhill.

A roller coaster filled with people has been raised, with great creaking and clacking, to the highest roller-coaster hill. But the gears and chains that pulled it up don't go beyond the top of the hill. There is no more need for them. As the roller coaster passes the top of the hill, stomachs float and people scream in delight as the cars speed downward.

These three situations have motion in common—downward motion. This chapter takes a close look at such motion.

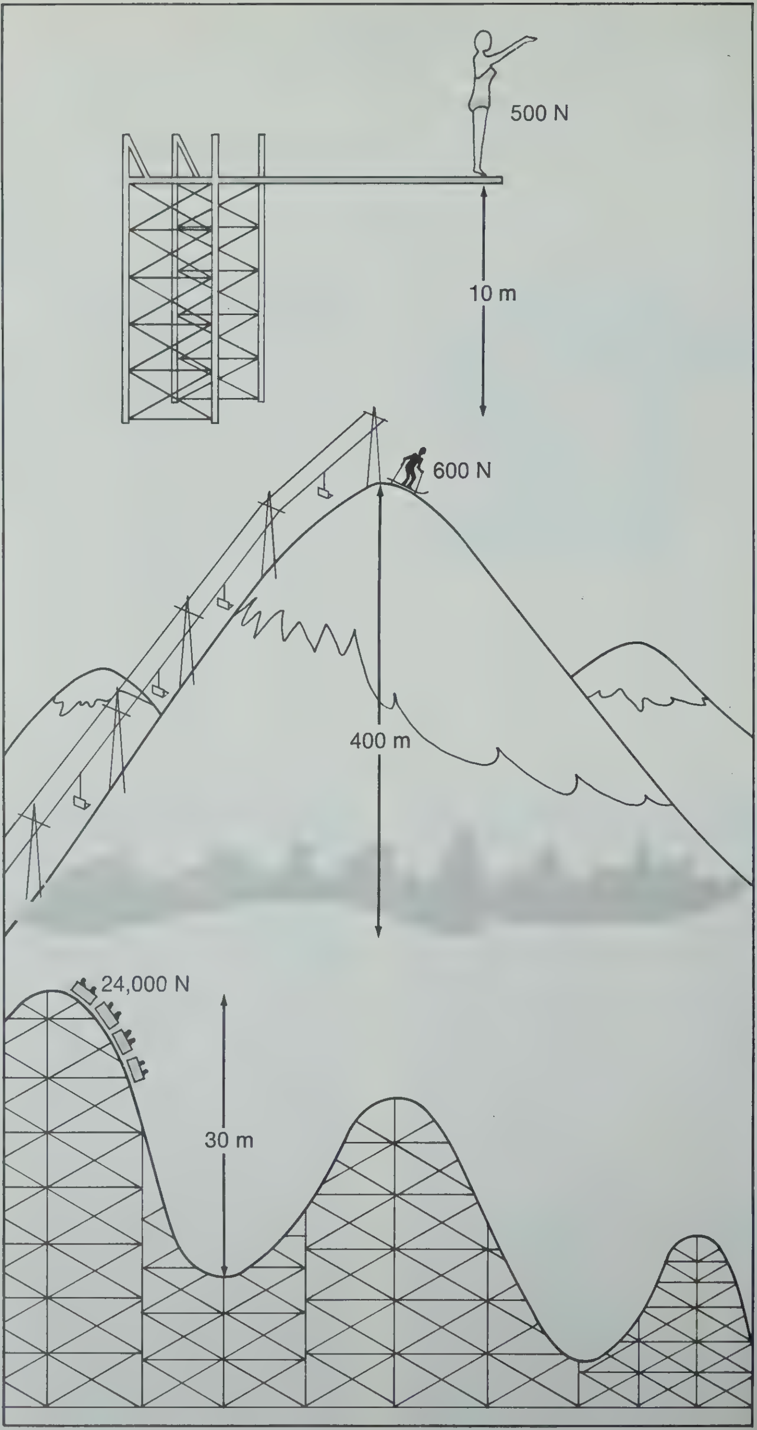
Work, falling people, and dropping things

Before a diver can dive off a platform, a skier ski downhill, or a roller coaster speed down its track, the same kind of thing has to happen. The diver has to get to the top of the platform. The skier has to get to the top of the run. And the roller coaster has to reach the top of its high first hill. Some kind of force has to be applied over a distance to do these things. That is, work has to be done in each case.

Consider the diver first. If she weighs 500 newtons, how much work must she have done to climb to a diving platform 10 meters high?

If the skier weighs 600 newtons and the ski hill is 400 meters high, how much work was done on the skier by the tow bar?

If the total weight of the roller coaster is 24,000 newtons and the top of the roller-coaster hill is 30 meters above the starting point, how much work must have been done on the roller coaster by the gears and chains?



What is needed for work?

You have probably heard people say many times that you should eat; you need energy. Sometimes you don't feel as though you have enough energy to get up in the morning. This something called energy seems to be needed to keep you going.

Electric motors also need a source of this something. Once the motors have this energy, they can do work. For example, they can lift objects, as do the ski tow-bar motor and the roller-coaster motor.

But what does this common idea, "energy," really mean? It seems to have no mass and you can't touch it. But you can easily see and feel its effects on many different objects and materials.

For the study of motion, you can look at energy as an invisible property that enables its bearer to do things. The diver has energy: she can move herself up to the diving platform. The moving parts of electric motors have energy: they can move a roller coaster uphill.

Anything that has *energy* can *do work,* in the sense that it has the ability to move either itself or some other object. This energy, the ability to do work, can occur in many forms.

Light hitting the sensitive material in a light meter generates electrical pulses to move the needle across the meter face. Light is a form of energy.

The electrical pulses in an electric motor can cause things to move. Electricity is a form of energy.

12·2a Light energy from the candle causes an electric current to flow through the meter, thereby moving the needle.

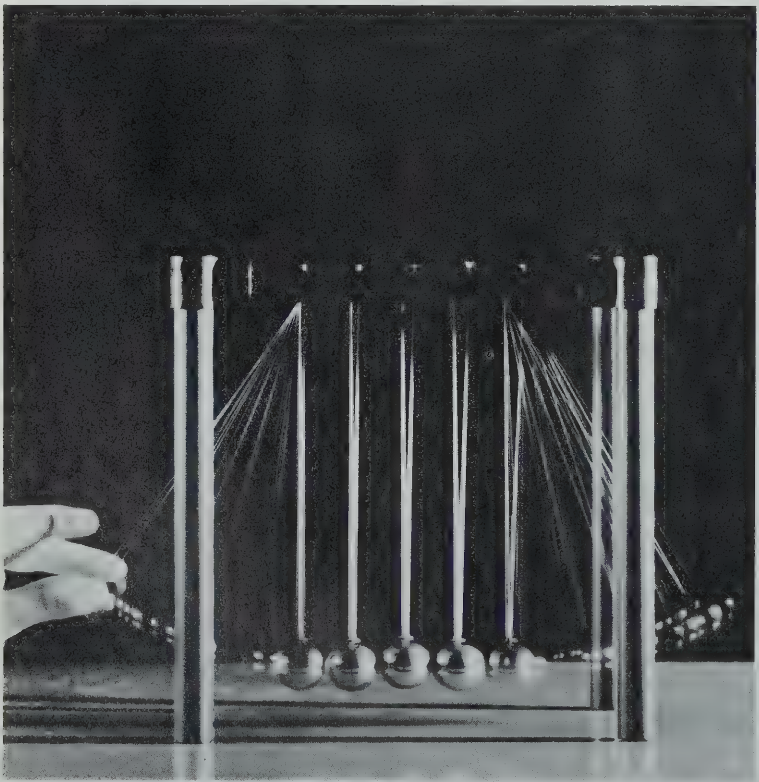
12·2b Electrical energy causes the blades in the blender to turn.

Something in motion, such as a car rolling down a hill, can bump into something else and make it move. Just plain motion is also a form of energy.

There are also several other forms of energy. But those will be discussed later in the book.

TEST YOURSELF

1. *Write down your calculations and answers to the questions on how much work was done on the diver, the skier, and the roller coaster (page 300).*
2. *What is meant by "energy"?*
3. *Name three forms of energy.*



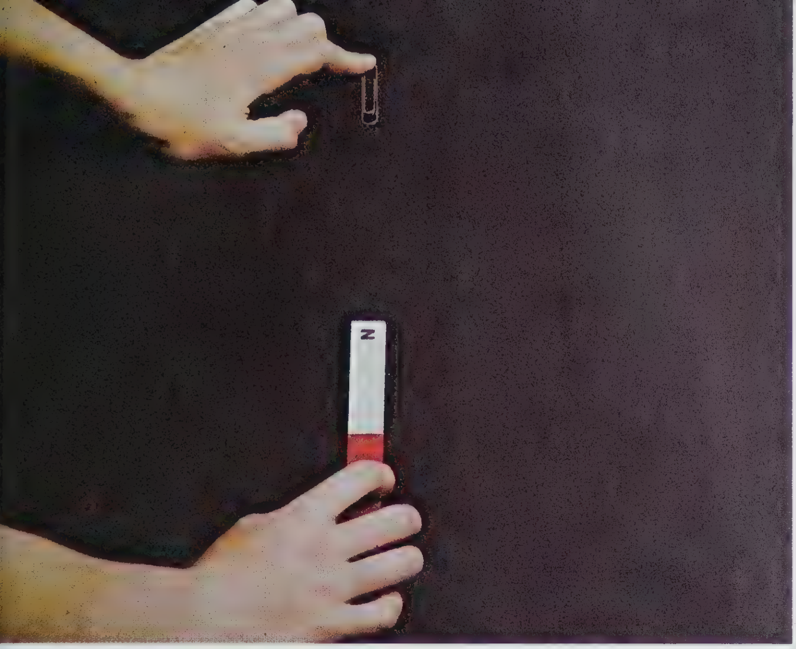
12·2c Energy of motion is transferred back-and-forth between the moving balls and the stationary ones.

To go on with the study of energy, you will need another look at force. Energy is defined as the ability to do work. And work, in the scientific sense, means applying force to something over a distance.

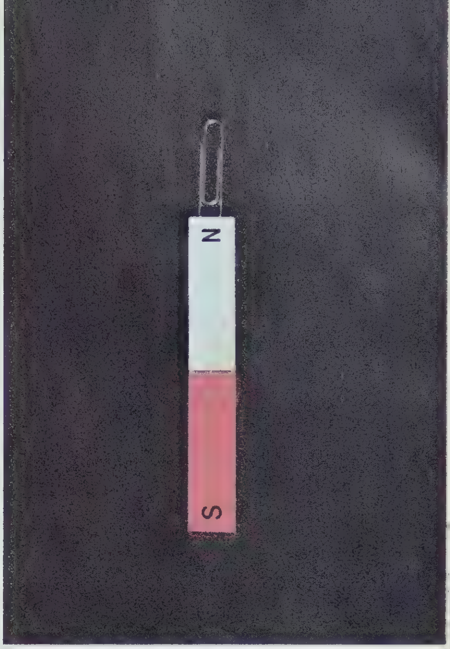
So far you have mainly examined forces that act directly on a particular object—pushing a car, pulling a laboratory cart, or hauling on a rope, for example. But earlier in this unit another kind of force was also mentioned—that of gravity.

The pull of gravity is measured in newtons in the metric system (or pounds in the English system) as are other kinds of force. The force of gravity changes the speed of falling objects, just as other forces change speed. Nothing touches an object in midair to make it fall—but you can see that it falls, just the same.

On the surface of the earth, the weight, or pull of gravity, for any one object is the same everywhere, for all practical purposes. But if this same object is put in a spacecraft and carried farther and farther from the earth, the pull of the earth on the object gets to be less and less. Finally the



12·3a The paper clip has potential energy when it is held in place in the magnet's force field.



12·3b When the clip is released, it is pulled to the magnet.

object is so far away that the effects of earth's gravity are practically impossible to measure. At this point the object is said to be weightless.

The object stops being weightless if it again comes within the pull of gravity of some large object in space. For example, as soon as a rocket comes close to another planet, the gravity of that planet begins to pull, or apply a force, on the rocket and to draw it toward its surface.

The area on and around the earth in which a gravity force is exerted on an object is called the gravity *force field* of the earth.

A spacecraft which is not measurably affected by the earth's gravity has, for all practical purposes, left the gravity force field of the earth. Then, as the craft comes within range of the other planet's gravity, it is said to be entering the gravity force field of that planet.

In theory, the gravity force field of any object goes out into space in all directions and doesn't end. But as the distance from an object increases, the effects of its gravity are so small that they can't be measured.

There is another force field with which you are familiar. It is the magnetic field around a magnet. The magnetic field is, in some ways, very similar to the gravity force field.

A magnet exerts a force on nearby iron or iron-containing objects. For example, if a paper clip is in the magnetic field of a magnet, the paper clip will be drawn to the magnet. You keep the paper clip from being drawn to the magnet if you hold on to it. By doing so, you apply a force equal and opposite to the effects of the magnetic field.

If the paper clip is right against the magnet, you have to apply a force if you want to move the paper clip away. Here you are doing work on the paper clip, since you are applying force to it over a distance. If you let go of the paper clip before it is out of the range of the magnetic field, it is again drawn right back to the magnet.

Now consider your shoe in the earth's gravity force field. It acts much the same as the paper clip in a bar-magnet's field.

Start with your shoe, without you in it. Place it on the ground, just as the paper clip was against the magnet. The shoe does not move. And if you leave it there, it never *will* move. It will take more than waiting to raise the shoe 1 meter off the ground.

Because the gravity force field pulls the shoe downward, if you want to move it upward, you must exert a force on the shoe. This force will have to be equal to the force of gravity acting on the shoe. But it will have to be applied in a direction opposite to that of the force of gravity, in other words, up instead of down.

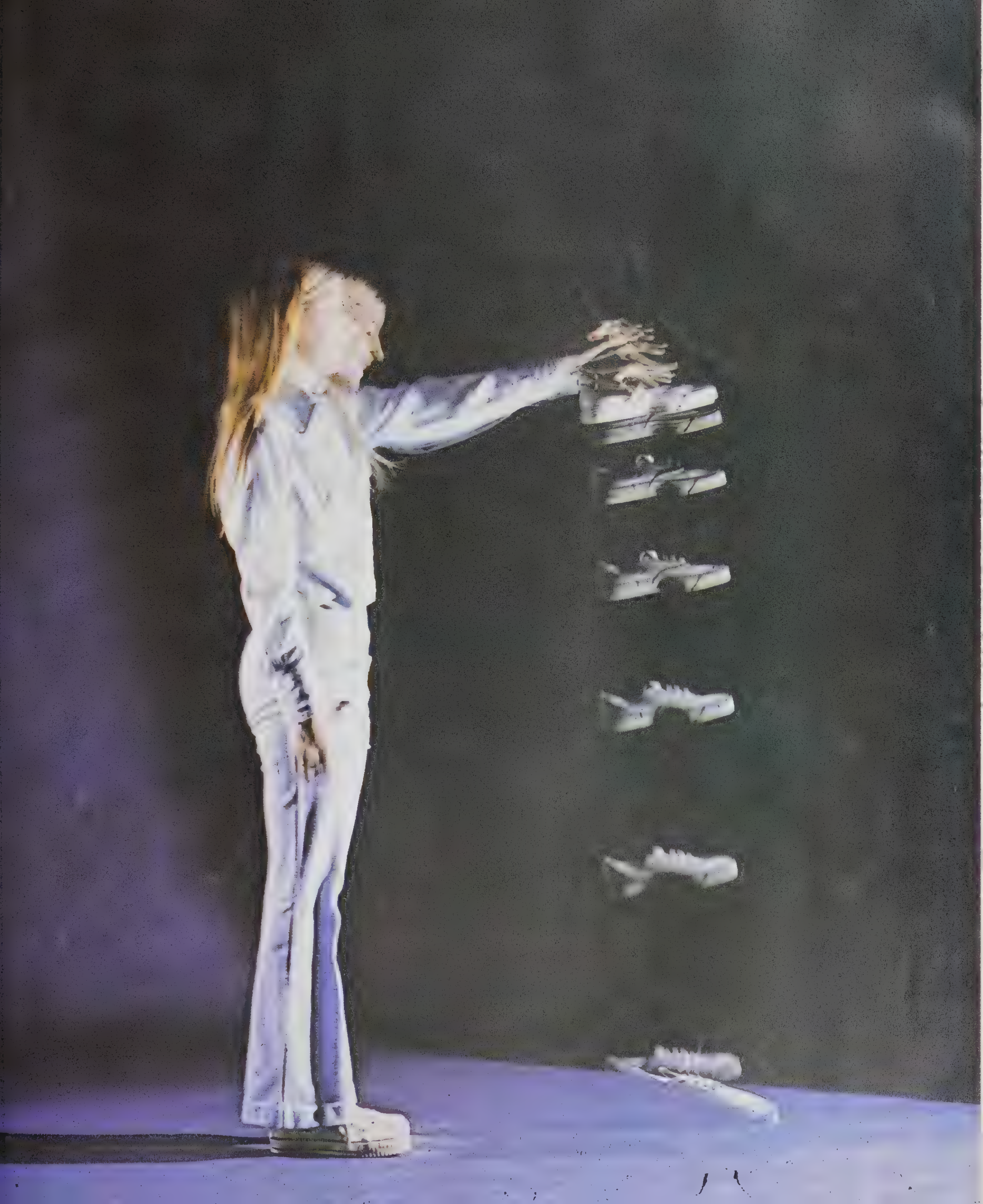
Say the force of gravity on your shoe is 2 newtons. In other words, your shoe weighs 2 newtons. If you lift your shoe 1 meter off the ground, you will have done 2 newton meters of work. But if you let go of your shoe, gravity takes over. Then your shoe is again pulled back to the ground. The gravity force field, unlike your force, is always present, always pulling.

TEST YOURSELF

1. *In what unit is the pull of gravity measured?*
2. *When any kind of force is applied to an object, how does it affect the speed of the object?*
3. *Is the pull of the earth's gravity the same on an object, no matter what distance that object is from the surface of the earth? Explain.*
4. *What is meant by ''the gravity* force field *of the earth''?*
5. *When you lift a book off the floor, what are you doing in terms of the earth's pull of gravity?*
6. *A nail is right against a bar magnet.*

   a) How is work (force × distance) involved when you pull the nail away from the magnet?
   b) To what force field is the work related?

12·4 When the girl stops holding her shoe, it is pulled back to the ground by the gravity force field of the earth.



An electric motor raising a roller coaster up a slope is using its ability to do work. But what happens just over the top of the roller-coaster hill, after the gears and chains of the motor are no longer in contact with the roller coaster? Of course the roller coaster zooms back toward the earth.

Your pay-off for the work that the electric motor does, as it moves the roller coaster against the earth's gravity force field, is motion.

Just before the roller coaster started down the hill, it had the potential to move toward the earth's surface. In the same way, a paper clip that you hold in a bar magnet's force field has the potential to move toward the magnet, if only you will let go of the paper clip. And a shoe you hold above the ground has the same potential to move back to the ground if you let go of it.

But how much potential for motion does a roller coaster have? Does it have the same potential for motion at the top of a 15-meter hill as it does at the top of a 25-meter hill? Does a shoe held 15 meters above the ground have the same potential for motion as a roller coaster at that height?

Before going on, let's give a name to this potential for motion. Since motion is a form of energy, the potential or possibility for motion is called *potential energy.*

An object has this potential energy because of the distance it has been moved against a force field. For example, a roller coaster has the potential to zoom back the 15 meters it's been raised above ground against the earth's gravity force field.

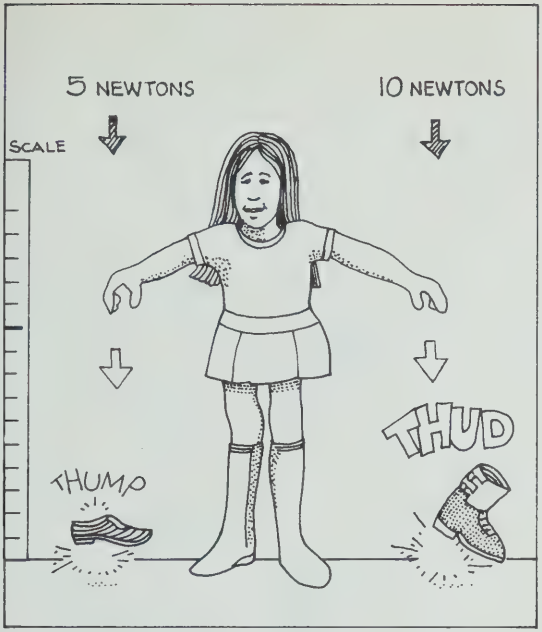
Now back to the "how much" questions about potential energy. Since you probably don't have a roller coaster handy to investigate the potential energy it might have, consider two shoes—one much heavier than the other. Say one weighs 5 newtons and the other 10 newtons. You lift one shoe in one hand and the other shoe in the other hand, each to a height of 1 meter above the ground.

If you let the shoes drop, which one do you think will make the greater noise when it hits the ground? Which would hurt you more if it accidentally fell on your toes? Finally, on which shoe did you do more work when you raised it a meter above the ground?

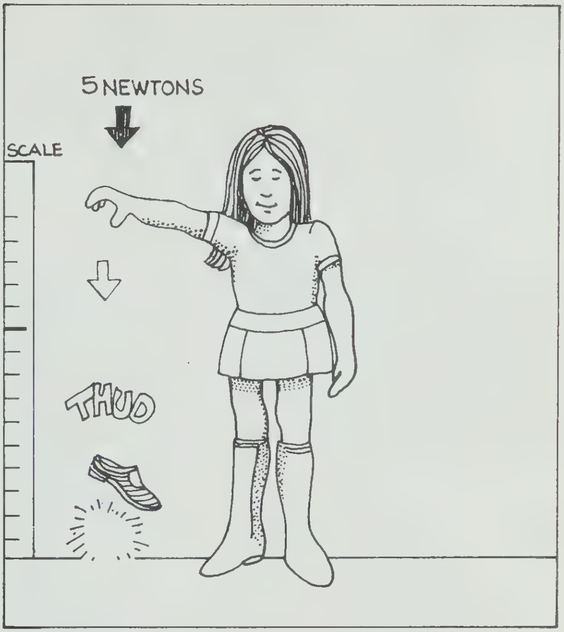
Next suppose you take the shoe weighing 5 newtons and raise it 1.5 meters above the ground. Imagine you are really accident prone and once again you let the shoe drop on your toes in the same way.

You can think of the "ouch" you feel as a result of the shoe's work on your foot. It pushes skin and muscle and bones through a short distance, while your nerves tell you about it. When this shoe falling 1.5 meters hits your foot, do you think your toes will hurt more or less than when they are hit by the same shoe falling from a height of only 1 meter?

Compare these "ouches" with that from the 10-newton shoe falling from 1 meter. In which of these three cases did you do the most work on the shoe to raise it before you dropped it?



12·5a



12·5b

The shoe on which you did the most work would hit your toes with the biggest "ouch" if it landed the same way. So that shoe must have had the most potential for "ouch," or, really, potential energy, before you let it fall.

So the more work done on the shoe to lift it to a certain height, the more potential energy that shoe has. In fact the same units of measurement that are used for work can also be used for potential energy. Thus the 10-newton shoe lifted 1 meter can be said to have 10 newton-meters of potential energy. The 5-newton shoe lifted the same height had 5 newton-meters of potential energy. And the same 5-newton shoe lifted to a height of 1.5 meters had 7.5 newton-meters of potential energy.

TEST YOURSELF

1. *What is potential energy?*
2. *How does an object get potential energy?*
3. *What is the potential energy of a 24-newton object that has been raised to a height of 4 meters?*
4. *What do the following have in common?*
   a) A rock held above the earth
   b) A piece of iron held near one end of a strong magnet
   c) The north pole of a magnet being held near the south pole of a stationary magnet.
5. *What would happen in each of the items in question 4 if the object were released?*
6. *A person has rolled a cart up a ramp to a platform. If the cart weighs 850 newtons and the platform is 3 meters high, what is the potential energy of the cart?*

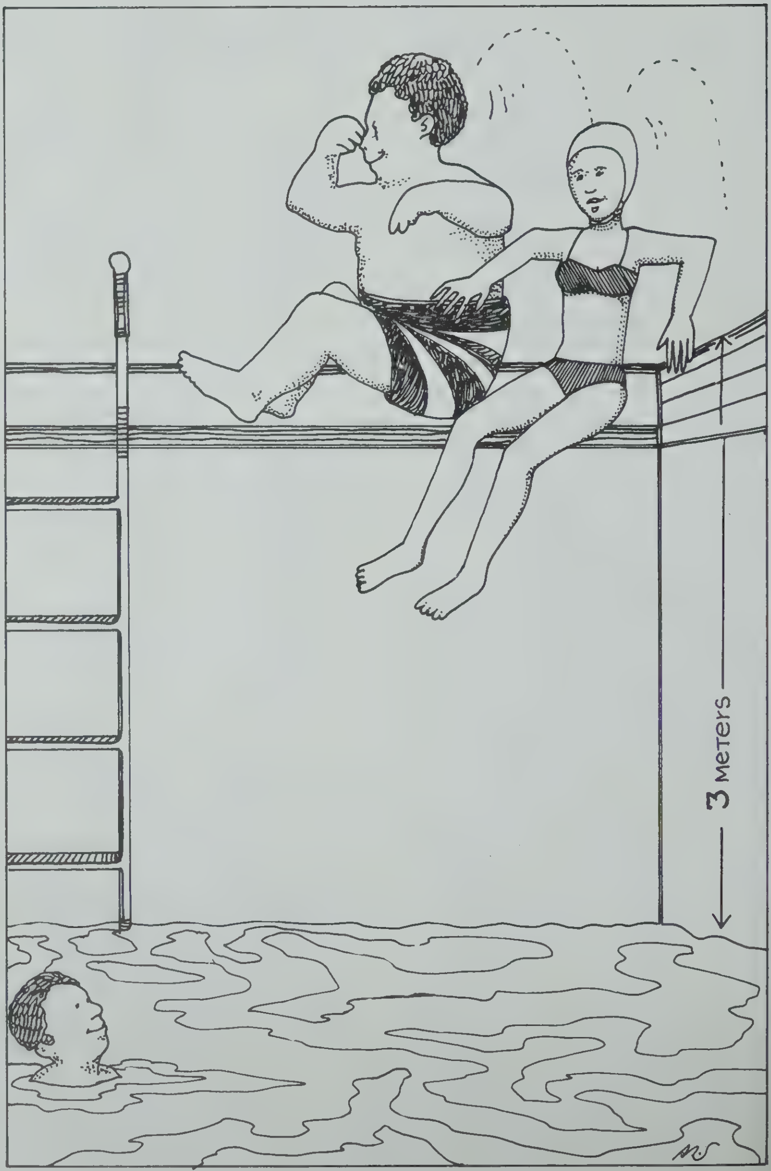
Mass, weight, and energy in falling things

Sandy and John are standing on top of a 3-meter diving platform. John is twice as heavy as Sandy. He challenges Sandy: "Let's jump off the board at the same time. I bet I'll hit the water first."

"And I bet I'll be first," comes the quick reply from Sandy who is lighter and slimmer. Who do you think made the better bet?

Here is John's reasoning: He knows that his mass is 80 kilograms and that his weight is about 800 newtons on the surface of the earth. (He's never weighed himself anyplace else.) He also knows that Sandy weighs only about 400 newtons and has a mass of 40 kilograms. John reasons that, since he weighs twice as much as Sandy, the earth is pulling on him with twice the force it is pulling on Sandy. So he should reach the water before Sandy if they jump at the same time.

Sandy, however, has a different idea. She's trying to remember what she read about mass, especially the part that goes, "The more mass an object has, the harder it is to start that object moving or to stop it once it is moving."



12·6

Sandy is thinking, "Since John's mass is twice mine, John's motion will not change as fast as mine. So I'll get to the water first."

So John yells to their friend Jerry, who is already in the water, "Call off a start and then tell us who hits the water first." As they hear Jerry holler "Go!" both jump off the 3-meter platform. What do you think Jerry reported?

Another question about falling might give you a clearer view of what happened. Were John and Sandy falling as fast at the beginning of their fall as they were just before they hit the water? To answer this question, think back to what you learned earlier about the effect of force on speed.

While Sandy and John were falling, the force of gravity was acting on them. A force acting on an object changes that object's speed. So as Sandy and John were falling, and the earth's gravity kept exerting an unchanging force on their mass, they kept going faster and faster.

John weighs twice as much as Sandy. That means that the earth was exerting twice as much force on him during the fall as it was on Sandy. So it doesn't matter that he has twice Sandy's mass (difficulty of being started or stopped). John's speed while falling increased *at the same rate* as Sandy's speed increased! John, who has more mass, received more force to move him to the ground. But Sandy, though easier to move, received less force to do the job.

Now let's put together all these ideas. John and Sandy jumped off at exactly the same time and in the same way. Their speed while falling increased at the same rate. And they both fell the same distance. Did either one of them hit the water first? *Or* did John and Sandy hit the water at the same time?

Now for still another question. Will Sandy and John have the same amount of energy when they splash down? For example, whose feet will hit the water harder? Do you remember who started with the most potential energy—that is, who had to do the most work getting up the 3-meter platform?

TEST YOURSELF

1. *A 40-newton package and a 70-newton package are on a shelf 3 meters from the floor. If both were pushed off the shelf, which package would have the most potential energy at the start of the fall?*

   Explain your answer in terms of the work that must have been done on the packages to raise them to the 3-meter-high shelf.

2. *The package that weighs 40 newtons is the same shape and size as the package that weighs 70 newtons. And the mass of the 40-newton package is about 4 kg and the mass of the 70-newton package is 7 kg.*

   If both packages are pushed off the 3-meter-high shelf at the same time, *will they both reach the floor at the same time?*

   Explain your answer in terms of the force of gravity acting on both packages during their whole fall. *(Continued on page 310.)*

ON YOUR OWN

Drop some change

Drop a quarter and a penny together from a height of at least a meter. Do they hit the ground at the same time?

Then drop a quarter and a small piece of paper together from the same height. Do these hit the ground at the same time? Can you explain your results?

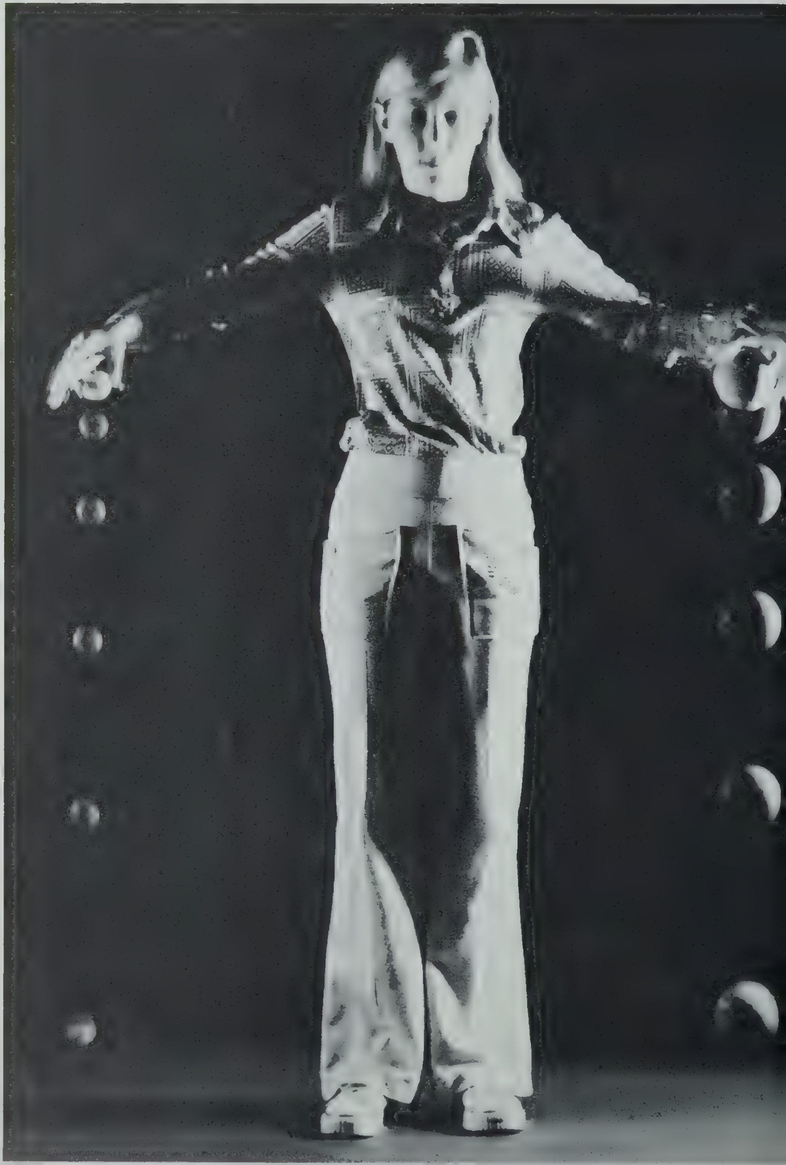
3. *Do you think the 40-newton package and the 70-newton package will hit the floor with the same "oomph"?*

   Explain your answer in terms of the potential energy both packages had at the beginning of the fall.

4. *Now for a bit different twist: A 5-newton box is pushed off a 2-meter-high shelf. An identical 5-newton box is pushed off a 5-meter-high shelf.*

   Will both boxes be moving at the same speed when they hit the floor? If not, which one will be moving faster?

   Explain your answer in terms of the change in speed caused by gravity.



12·7

An historic overview of some thoughts on gravity

The Invisible String

In this chapter you have investigated the result of work done on objects in raising or lifting them against the pull of gravity. Once the work has been done on the objects and no restraining force is applied to them, the force of gravity pulls on the objects, setting them in motion.

Arguments concerning gravity—what it is and how it works—have existed for thousands of years. Even though people have always experienced downward forces on themselves and on the objects they try to lift and throw, they have groped for precise statements concerning the pull of the earth.

The ancient Greek philosopher and scientist, Aristotle, explained why things fall by simply saying, "They seek their natural place on the ground." Although he was a great and logical thinker, he would have falsely thought that of two masses, one greater than the other, the greater one would reach the ground first if both were released from the same height at the same time.

He probably had in mind the general observations that stones fall faster than feathers and leaves fall slower than acorns. For generations people assumed that Aristotle's statements were correct. They thought that objects fall with speeds proportional to their mass.

In the seventeenth century, the Italian scientist Galileo realized that Aristotle and his followers had let air resistance confuse their ideas about falling objects.

What is air resistance?

Air resistance is what you feel against your face when you are running fast or pedaling a bicycle. As you push forward through the air, the air in front of you exerts a greater force than the air behind you. You feel the difference. You can compare this effect of air with the resistance of water that you feel when you try to walk in waist-deep water.

There is another effect of air resistance that you can't feel as readily when you are running or pedaling a bicycle. This effect is that of friction. The surface of a moving object and the layer of air around the moving object slide past each other. Friction occurs between air and the object moving through it. Such friction tends to hold back something moving through air.

Now back to Galileo

Galileo suggested that for small objects of large mass, air resistance has little effect. For example, two rocks—one with more mass than the other—will fall together through a short distance.

Galileo further extended his imagination to guessing what would happen if objects were to fall freely in a vacuum (no air to resist the object's motion). From this thought experiment, he reasoned as follows: All objects fall with the same motion. So objects started together, fall together. And falling objects gain speed at a steady rate and will increase in speed the same amount each additional second.

There is a legend that Galileo dropped some objects from the Leaning Tower of Pisa in Italy to see if they would hit the ground together. One object was supposed to have had a small mass; the other, a large mass. Galileo probably did not do such an experiment. It is more likely that he reasoned it through.

Recently, though, some American astronauts did do just that kind of experiment on the surface of the moon. Since there is no atmosphere on the moon as we know it here on earth, there is no air resistance. When the astronauts dropped a hammer and a feather at the same time, they both hit the moon's surface together.

If you were watching the astronauts on television at that moment, this experiment probably seemed strange. Here on earth, we are used to seeing a feather float slowly to the ground when it is dropped. That's exactly what the feather is doing—floating. Air resistance keeps it from plunging down to the earth's surface the way a hammer does.

The situation is similar to watching a large flat object, such as a sheet of metal, sink slowly to the bottom of a tank of water, while a metal ball sinks immediately. On the moon's surface, however, nothing is interfering with the moon's force of gravity on the feather and the hammer. So they drop together, as Galileo predicted a long time ago.

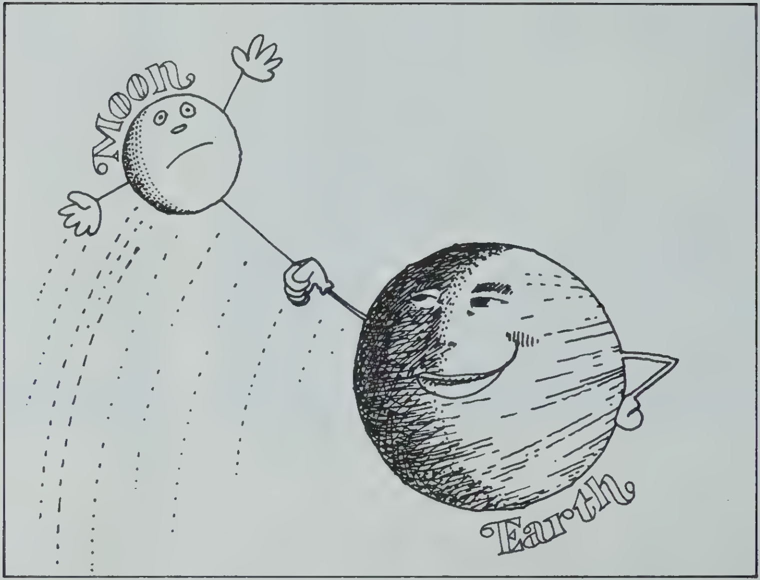
12·8 Astronaut on the moon dropping hammer and feather at the same time.

The predictable force

Isaac Newton was born in England in 1642, the year of Galileo's death. Newton was fascinated with the study of how things move, especially toward the earth. He extended the idea of objects being pulled toward the massive earth. He suggested that such forces are exerted between all objects. He talked of the earth's pull reaching to the moon to control its path around the earth. He suggested that forces of attraction exist between the sun and the earth and all the planets.

Today, scientists have put these ideas of Newton's to use. For example, if a spaceship is to travel from the earth to Mars, the spaceship's path must be computed on the basis of all the small and large pulls exerted on it by all of the planets, the moons, and the sun.

The famous German philosopher Gottfried von Leibniz (līb′nits) attacked Newton's ideas. Leibniz agreed with Newton that an applied force can change an object's motion. But Leibniz, who lived during Newton's time, believed that the applied force must be one of contact, such as the force of a bat on a ball or a horse's pull on a cart. He laughed at Newton's belief that the force of gravity could act across the vast empty space between the sun and



a planet. Leibniz said that if Newton could explain how gravity works without contact, like an invisible string between objects in space, then he would take the idea of gravity more seriously.

There wasn't very much concrete data then to support Newton's views, so Leibniz's doubts are understandable. As a matter of fact, scientists are still trying new ideas and experiments to find out how gravity works.

There is one thing all scientists have accepted about the effect of gravity on the earth's surface. Any falling object will increase in speed at the same rate as any other object if we subtract any difference caused by air resistance.

The rate at which a falling object increases in speed is called *g*. (*g* comes from the word *gravity*.) At the surface of the earth, the quantity *g* has the value of almost 10 meters per second for each second an object is falling. This definition states that the speed of any falling object increases by 10 meters per second every second during its fall if the object is compact enough so that air resistance does not interfere very much.

Applying the concept of ***g***

A Backward Shove When Going Forward

Imagine yourself strapped in a race car, waiting for the starter's signal. A force due to gravity pulls you down against the seat. A measurement of that force is your weight. The seat in which you're sitting is supported by the car. The car is supported by the earth's surface. In a way, both the seat and the car are exerting an upward force on you equal to your weight. Otherwise you would be falling toward the earth. But you remain in one spot—in this case, the seat.

The starter signals you to go. Your foot goes down on the accelerator. The wheels spin and screech as the huge racer engine thrusts the car forward. Instantly, a breathtaking force thrusts you against the back of the seat. But it's not the force of gravity. Out the corners of your eyes, you see the trees and ground streaking past. You realize that the force pushing you and the back of the seat together is due to the racer engine. It's forcing the car, with you in it, to move faster and faster.

12·11

Imagine now that you are strapped in a seat in the nose cone of a huge two-stage rocket. The rocket is about to blast off from earth. This time you are strapped lying on your back. So the back of the seat is exerting an upward force on you equal to the downward pull of gravity. The countdown begins.

10 . . . 9 . . . 8 . . . 7 . . . 6 . . . 5 . . . 4 . . . 3 . . . 2 . . . 1 . . . Ignition!

The entire supporting tower trembles as the thrust of the spacecraft's powerful engines drives it upward from the launching pad. As the spacecraft lifts off slowly, the seat pushes on your back with a force just slightly greater than that due to gravity. This extra upward force is not due to the support given the spacecraft by the earth's surface. This upward force is due to the thrust of the rocket engines.

Gradually the engines increase their thrust. As this happens, you and the spacecraft are lifted faster and faster through the atmosphere. Each second you are increasing your speed up and away from the earth at about 20 meters per second. That's twice the rate at which an object falling freely toward earth increases in speed.

During this time, the force between your back and the seat is three times that produced by gravity when you were sitting on the earth's surface. A third of this force produced by the rocket's engines is needed to overcome the force of gravity. The other two-thirds of the force is causing your increase in speed.

The engines keep increasing their thrust even more. So your upward speed increases at a greater and greater rate. At the same time, the force between your back and the back of the seat keeps increasing accordingly. Then the rocket engines slow down a bit so that you're increasing in speed at a slower rate. And the force between the seat back and you decreases. The first stage of the rocket separates from the second stage and from the spacecraft nose cone. It's thrust back toward earth by the separating explosion.

The thrust of the rocket's first stage backward speeds you upward with a lurch. So the force between you and the seat back increases again.

All these changes in the force with which you feel yourself pushed against the seat in the spacecraft (and in the racing car) are usually expressed in g's.

The how's and why's of *g*

In the previous section (page 314), g was defined as the rate at which a falling object on earth increases in speed. That value is about 10 meters per second for each second of the fall. In a mathematical expression, $g = \frac{\text{Force}}{\text{Mass}}$. In the case of a falling object, the force value in this formula is the weight of the object. That force value is divided by the object's mass. The result will be g.

However, this same formula can be used when the force value is not that of the pull of gravity, but of something else. For example, force can be applied by the motor of a racing car or by the rocket engines of a spacecraft.

Let's take the case of the spacecraft. At one point the engines caused it to speed up at twice the rate at which an object falling toward earth increases in speed. In this case the craft is said to be speeding up at 2 g's.

To double the rate at which the spacecraft speeds up, its rocket engines have to double the speeding-up force. You can feel this doubled force by the increased force you feel between your back and the seat in which you are strapped. When the engines speed up the spacecraft 3 g's and then 4 g's, the force between your back and the seat increases three times the force of gravity, then four times the force of gravity.

Space scientists and other people who study motion use the term g in a shorthand way. They express the force that people feel on themselves in a speeding-up vehicle in terms of g. For example, they say you feel the force of 2 g's if you are speeding up each second at the rate of about 20 meters per second. That's twice the rate an object falls toward earth near the earth's surface.

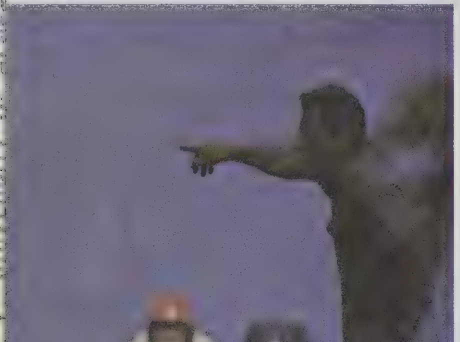
A thought and discussion question

What's the Hurry?

Ever since the first hairy *Homo sapiens* hitched a ride on a helpful four-legged friend, it seems that people have found ways to go faster and faster. We laugh at the Victorians who warned that humans were never intended to hurtle along at twenty miles an hour.

But the conquest of speed has had its ironic twists. "Progress" has brought New York City from an average traffic speed of eleven miles per hour in 1911 to its modern average—six miles per hour.

A similar thing has happened on the artificial lakes of southwestern United States. These are the favorite playgrounds of the super powerboats. People get out as early as eight o'clock in the morning to speed themselves and water skiers across the water at some sixty miles per hour. They have to start early. By eleven o'clock the water is so churned up that the boats can barely move.



12·12 Traffic jam

As for speed in the air, big jets go faster than anything else available to the average person. But getting to the take-off in a big-city airport is a problem. The roads to the airport are often jammed. Once you get on the jet, it has to wait its turn on the runway. And once the jet arrives at its destination, there is the possibility of having to circle and recircle over the airport until ground control gives the jet its turn to land.

One might well wonder, why do people get into so much trouble just for wanting to go fast? Speed is, after all, a fairly common and natural desire. Even the family dog loves to hang its head out the car window and let its ears flap in the breeze. And the youngest baby gets a kick out of being swung overhead.

Of course, by the time the baby is grown-up and of driving age, the desire for speed has been boosted considerably by the advertising of the various makers and sellers of speed machines. Many items, such as snowmobiles and high-performance car accessories, are pushed on the basis of speed. The high-power racer's image is stressed. The cars are flashy. Powerboats are bright and sleek-looking, with engine to spare. And for some there is the status of a private plane.

How could we calculate the real cost of that flashy new machine on the driveway, harbor, or airfield? Air and water pollution must certainly be added in. Even a major auto company admits that cars are responsible for nearly 40 percent of the air-pollution problem in many areas. And Jacques Cousteau, famous sea expert, has made an interesting comment. He says that when the Dutch tanker *Marpessa* exploded with 207,000 tons of crude oil aboard several years ago, the resulting pollution was only about 4 percent of what the oceans receive from pleasure boats *every year.*

It would slow us all down—some say too much—to use public transportation, bicycles, and foot power to do our traveling within a city. And it would cost a lot to develop a private or public vehicle for longer distances that will really be pollution-free. But what about the steel, oil, and other materials that are being used just so we can go a little faster? And how much do we care about the pollution caused by our speed machines?

Still another cost is the good farmland, city dwelling space, and natural wilderness used up by the spread of the giant throughways in our country. They do help cut down on time spent traveling from place to place. But at what cost?

Noise from boats, autos, small airplanes, and large jets is another cost that ranges from a nuisance to a shattering experience for those who live in sonic-boom territory.

Also consider that in most states the taxes from gasoline sales are put in a road-building fund. So none of that money spent on speed can go for other human needs.

Perhaps there are other ways of using motion to get the pleasure that comes from speed—ways that won't have as high a cost. Many people are becoming committed to a practice of "free energy." They want to develop and use sources of motion and energy that don't use up the earth's resources. Walking, bicycling, sailing, and mountain climbing can all be fun. And these use up very little of our natural resources and cause no pollution.

But some will still say, "Oh, no, man—I want to go *fast*, I want to get where I'm going *now*."

What do you think?

If you would like to read more about this subject, look up the following topics in *The Readers' Guide to Periodical Literature*, in your library card catalog, or in an encyclopedia:

Air pollution
Automobile
Aviation
Ford, Henry
Noise
Pollution, air, and marine
Powerboating
Racing, automobile
Steam car

Unit 4: Heat

Have you heard comments like these?

“I wish someone would turn up the *heat* in here I'm *freezing*.”

“The argument's getting too *hot*. Let's talk about something else until everyone *cools* down.”

“She couldn't come to school today. She caught a *cold*.”

“He has no sympathy at all. He's just plain *cold*.”

“The *heat's* on at work and I couldn't relax for a minute.”

“That salesman is a *cool* character, nothing ever bothers him.”

“That new Mexican restaurant is great. I love *hot* food.”

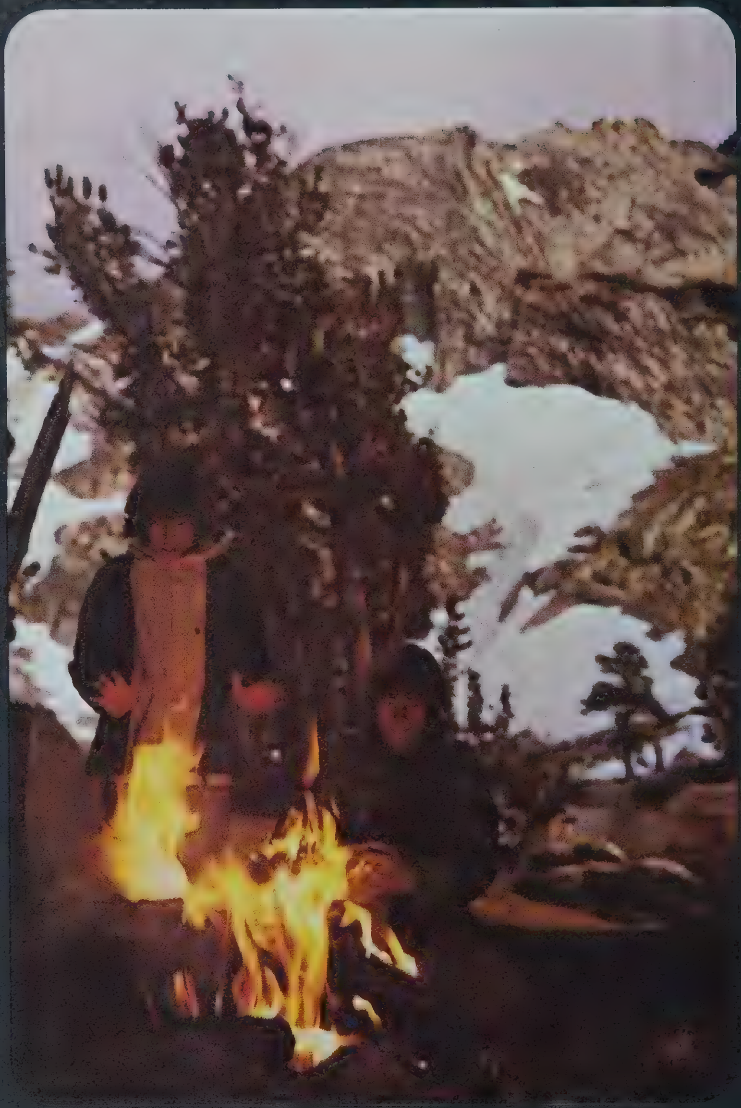
“The challenger was knocked out *cold* in the 10th round.”

“Some political speeches are just a lot of *hot* air.”

“I'm ready for opening night. I have my lines down *cold*.”

All of these people are talking about heat and cold. Or are they? What does “heat” mean? and “hot”? and “cold”? All of these words are used properly but differently in the examples. These words will also be used in this unit, but in some special ways.

a-b.



a. A campfire in snowy wilderness says warmth.

b. So does a cup of hot chocolate after a walk in the rain.

c. The heat from the sun has caused the evaporation of the water that covered this land for a while. The water in the remaining mudhole is boiling.

d. Water can be found between layers of rock under the surface of the earth. The temperature in the lower layers becomes so high that the water boils and escapes as steam. Such an escape route is called a geyser. As the steam reaches the air, some of it becomes liquid again and falls as mist.

e. Under ordinary conditions, most metals are solid. But even metals become liquid at extremely high temperatures.

f. Heat can be caused by many things. For example, sparks fly when two solid metal surfaces rub against each other fast enough.

c

d

e

f

Chapter 13: Temperature

13

Suppose it's a really hot summer day. You've been walking in the sun a while. You're thirsty and tired. But just at that moment you happen to be in front of a drugstore which has a snack counter. The thought of an icy drink perks you up. You could even put the cold, wet glass against your forehead. That would feel good.

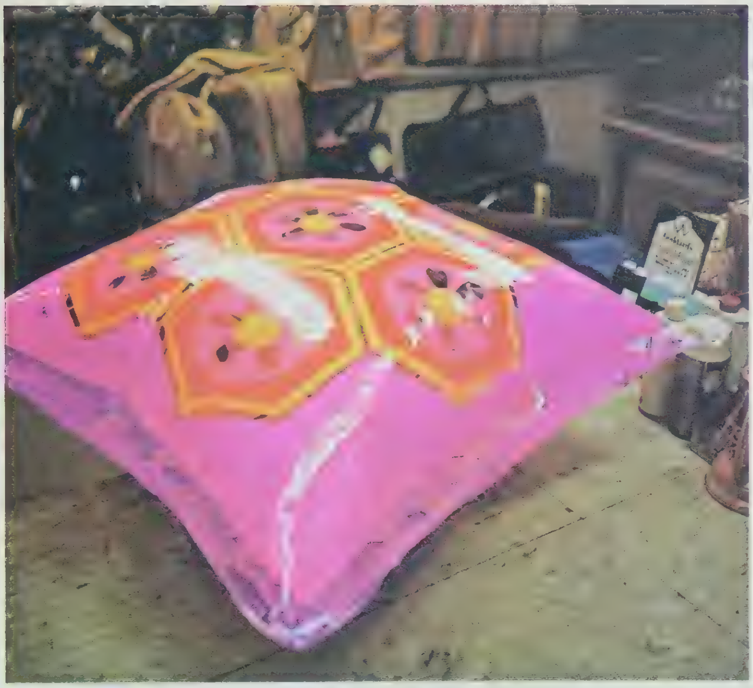
As you open the door to the store, a wonderful blast of cool air hits you in the face. You plop down on the counter stool and say something about how nice and cool it is in there. The waitress looks surprised and says, "For the last few hours I've been meaning to ask the manager to turn up the air conditioning. It's too warm in here."

Obviously hot, cool, and cold aren't very accurate terms. In the case above, who is right? Is it cool in the store? Or is it warm? This chapter is about a more reliable way to communicate how hot or cold something is.

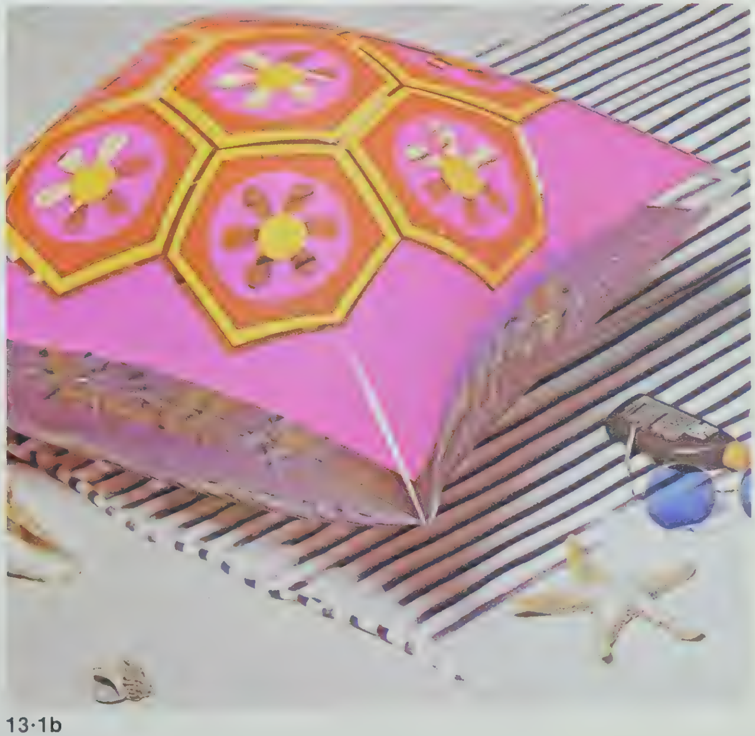
An effect of heat

On another hot summer day suppose you're going out for a swim. On the way, you stop in an air-conditioned store to buy a thin-walled plastic beach pillow. Without air in it, the pillow is just a plastic sack. So the clerk lets air into it from a tank. However, she doesn't seem to blow it up all the way. The corners are still a bit wrinkled (figure 13·1a). But after you take the pillow out of the store and into the hot sun for a while, the corners become smoother.

As you walk along, you step on some soft tar oozing out between the sections of the sidewalk. On the way home from your swim, in the cooler evening, the tar is no longer flowing out of the cracks. And if you think about it, you might recall that in cold weather hardly any tar shows above the cracks.



13·1a



13·1b

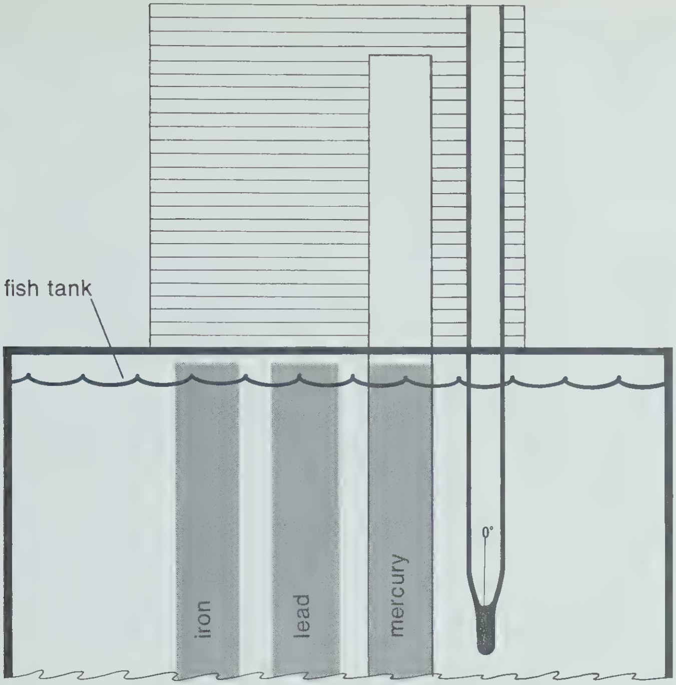
If you ever cross a bridge, look for the toothlike seams that run across most bridges. The teeth clamp tightly together in the summer. But in winter there is usually a space between them (figure 13·2).

The air in the beach pillow, the cement and tar on the sidewalk, and the cement and steel on the bridge reacted similarly to the effect of heat. Because of the way heat affects those materials, you could use them to measure temperature. You can also use water, alcohol, and mercury, the silvery liquid metal. In fact, you can use practically any material.

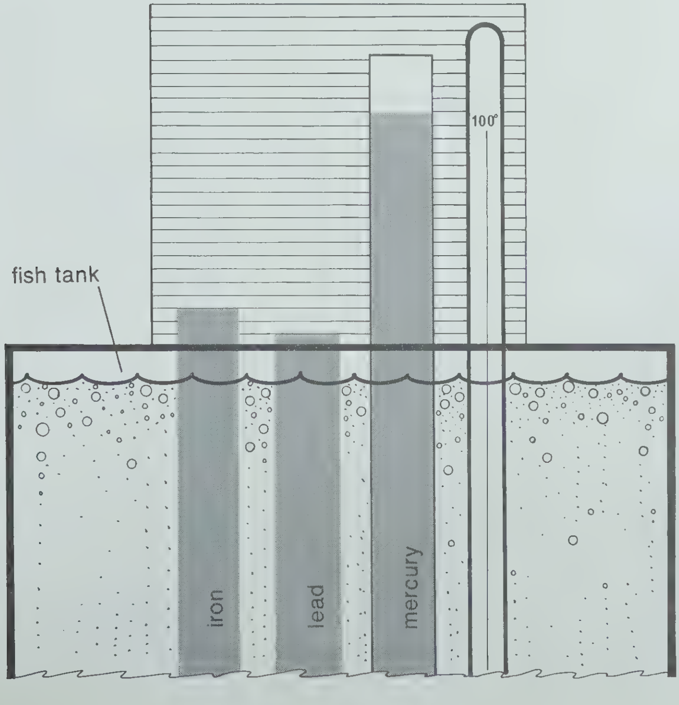
Figure 13·3 indicates why you can use all of these materials to measure temperature. In the first part, it shows an iron rod, a lead rod, and a glass tube containing mercury. All are almost totally submerged in a tank of ice water. The top of the column of mercury is level with the tops of the metal rods.

Part *b* shows the same metal rods and the tube of mercury almost totally submerged in boiling water. The drawing shows what happens to the length of the rods and the column of mercury. You can measure temperature by making use of this property, the action of materials when they are heated and cooled.

13·2 Notice the green water below the open expansion seam.



13·3a Iron, lead, and mercury in 0°C water.



13·3b Note what has happened to the iron, lead, and mercury in the above tank after the water has been heated to 100°C.

You can make a temperature measurer

There are many kinds of measurers or *meters* in the study of science. You can measure the intensity of light with a light *meter*, count coulombs per second with an am*meter* and measure energy per coulomb with a volt*meter*. And, of course, the instrument you use to measure temperature is the thermo*meter*.

You can make a thermometer from any substance with the properties described in the last section. That is, you can use any material that changes in length when its temperature changes. Such materials also change in *volume*, or amount of space they take up, with temperature changes. And your job will be simpler if the change in volume can be seen easily.

Your thermometer will be easiest to read if you make it out of the substance that has the greatest increase in volume for each rise in temperature (Table 1). In figure 13·3, the column of mercury increased in volume more than either of the solid metal rods. Since mercury is a liquid, you can easily make its increase in volume, or expansion, seem greater.

The bulb at the bottom of a mercury thermometer holds a reservoir of mercury. As its temperature rises, the mercury expands into a very narrow tube. So a small increase in volume shows up as a large increase in the length of the column of mercury.

The expansion of other liquids can be made to look greater in the same way as the expansion of mercury. Since you want your thermometer to be easy to read, it would be best to make it a liquid thermometer.

You could start with a narrow glass tube which has a bulb full of mercury at the bottom. The top of the tube should be closed. To make the tube into a useful thermometer you would need to put some numbers on it.

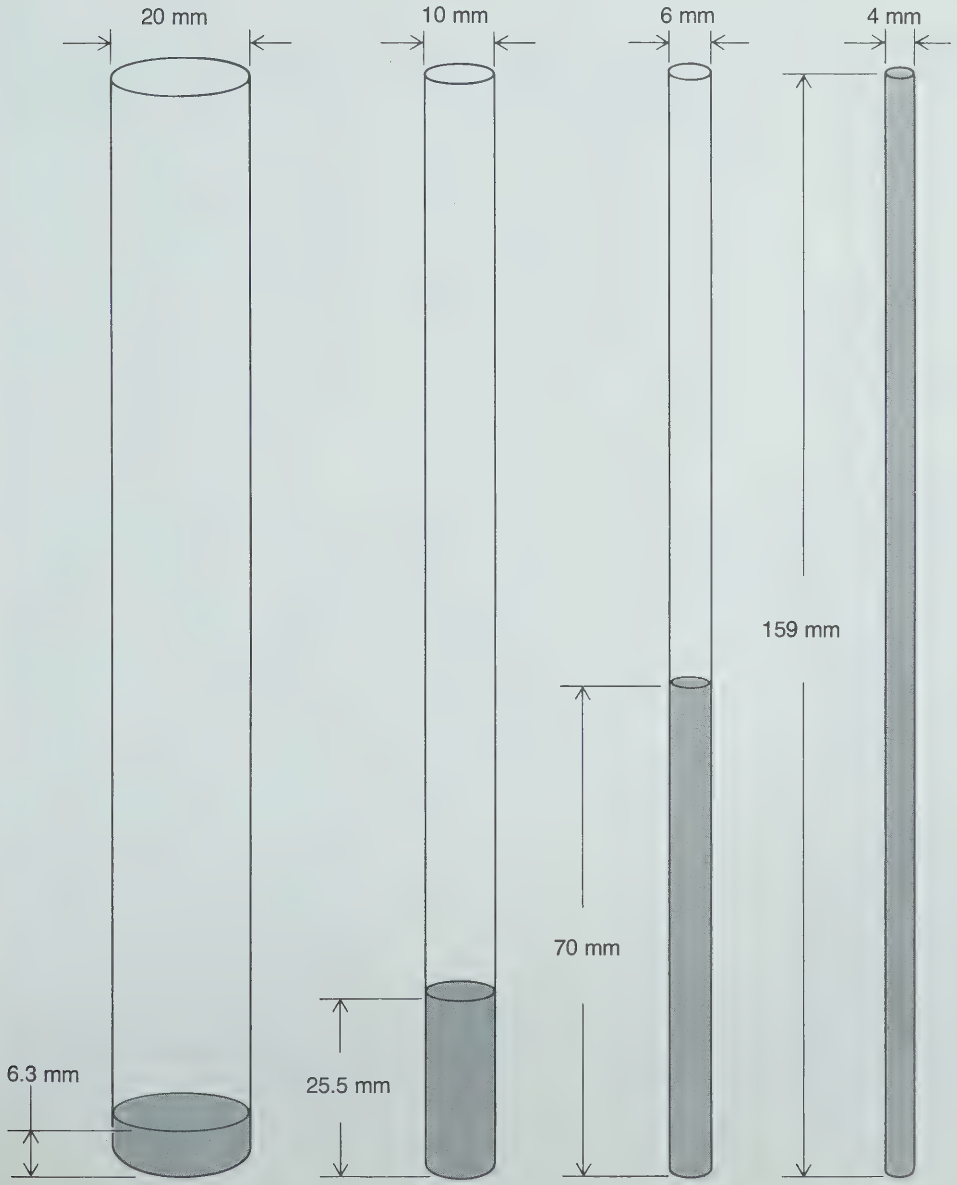
You can choose your own set of numbers or standards to identify temperatures on your thermometer. When you do this, you are *calibrating* your thermometer.

Table 1

Expansion of Some Common Materials

Material	Increase in length of 100-cm rod 0°C to 100°C	Increase in volume of 100-ml liquid 0°C to 100°C
Aluminum	2.4 mm	
Brass	1.9 mm	
Copper	1.7 mm	
Ethyl alcohol		11.2 ml
Glass, thermometer	0.8 mm	
Iron (steel)	1.1 mm	
Lead	2.9 mm	
Mercury		1.8 ml
Silver	1.9 mm	
Tungsten	0.4 mm	
Turpentine		9.7 ml
Zinc	2.6 mm	

13·4 The volume of 100 ml of mercury increases by 1.8 ml when it is heated from 0 C to 100 C. In a 20-mm diameter tube, that 1.8 ml forms a column around 6 mm high. However, in a 4 mm diameter tube, the same 1.8 ml of mercury forms a column about 159-mm high. By making the tube narrower, you can magnify the expansion of the mercury.

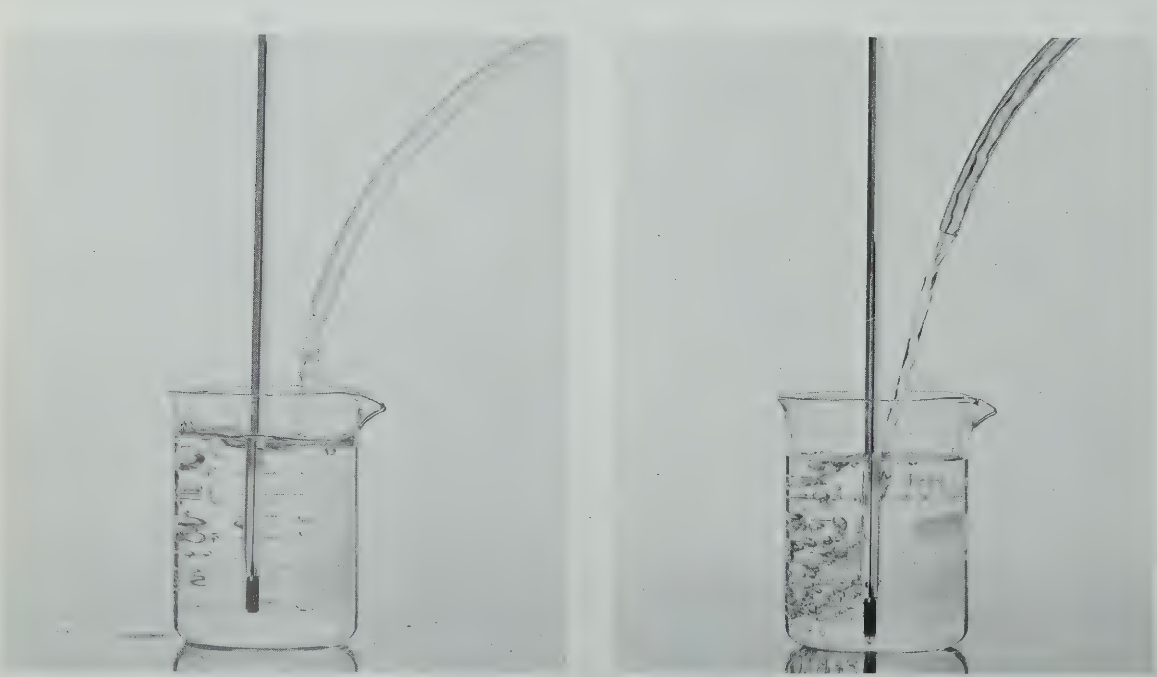


The top of your temperature measurement scale could be the temperature of the hottest water from a faucet. To find that temperature, you would hold your unmarked thermometer in a cup under the water faucet. You would run hot water into the cup until the mercury stops expanding (figure 13·5a). You could then mark the top of the mercury column.

The bottom of your scale could be the temperature of the coldest water from the faucet. For that temperature you would hold the thermometer in a cup under the cold water until the mercury stops contracting. You could make the bottom mark at that point (figure 13·5b).

Your thermometer would then be marked with the highest and lowest *reference points* on your scale. Reference points are just places to start from.

Once you have your temperature reference points, you can measure the relative warmth of things. For example, there is a range of warmness and coolness between the coolest water from the faucet (your bottom reference point) and the hottest water from the faucet (your top reference point). As you know, the mercury in your incomplete thermometer will contract and expand accordingly.



13·5 The faucet is high above the beakers. Plastic tubing is used to transfer the water from the faucets to the beakers so the water will not splash. Hot water is running into the beaker on the left; cold water into the one on the right.

To measure this expansion and contraction between the reference points, you can divide the distance between them into equal steps, or *degrees*. And, of course, you can then mark steps, or degrees, of the same size below the bottom reference point and above the top reference point. In this way you can measure things which are colder than the coldest water and hotter than the hottest water from the faucet.

You can decide how many steps you want to have on your thermometer. Your decision might be based on the distance between the reference points, and on the simplest way you can find to divide that distance into equal steps.

To make your thermometer easy to read you might decide to call the temperature of the coldest water 0°M (*M* for *My* scale). If you make this decision, whatever you measure that is colder than the water from the faucet would have to be less than 0°M. That is, it would have to be in minus degrees. For example, water from a puddle on a winter day might be −5°M.

You would also number each step in turn, up to the temperature of the hottest water, which could be 40°M or 100°M or whatever you decide.

Once the sections are marked, it is possible to measure temperature of all kinds of things in degrees M (figure 13•6). For instance, you could find the temperature of your classroom or of your own body in degrees M. You could also find the temperature of boiling water and of freezing water in degrees M.

If the M scale were an accurate one that could be easily reproduced, you might try to have it accepted for international use. For instance, if all the students in the world would accept the M scale, it might be adopted for international student use.

TEST YOURSELF

1. *Do you think a person living in the tropics and a person living near the North Pole would agree as to whether a 15°C (59°F) day was warm or cold? Explain.*
2. *What property makes materials useful in thermometers?*
3. *What is the main advantage of making a thermometer out of a liquid?*

13•6 Thermometer calibrated in °M.

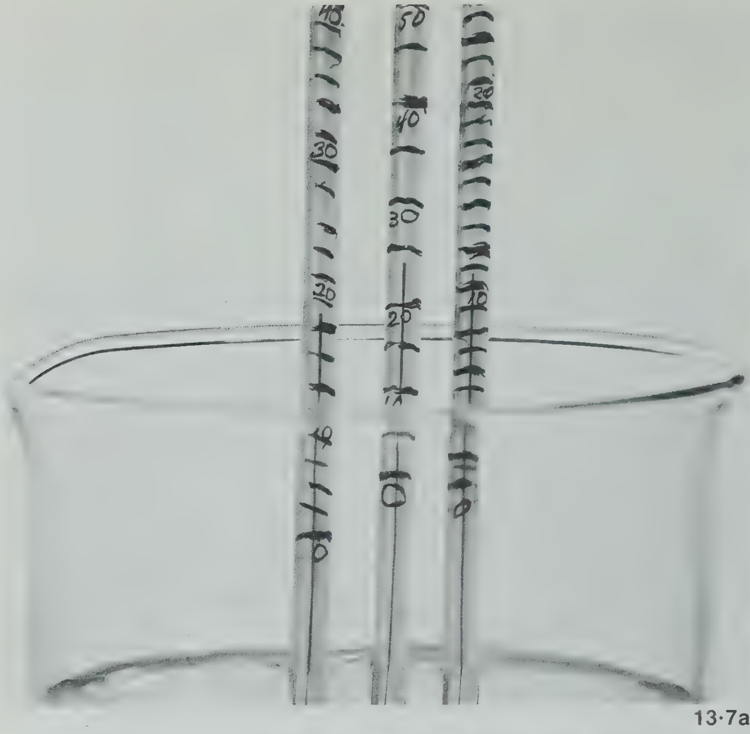
Somebody else's scale

When you made your temperature scale, you divided the distance between two reference points into equal parts to determine the expansion required for 1°M (*My* scale). These reference points would have to be used for every thermometer marked according to your scale.

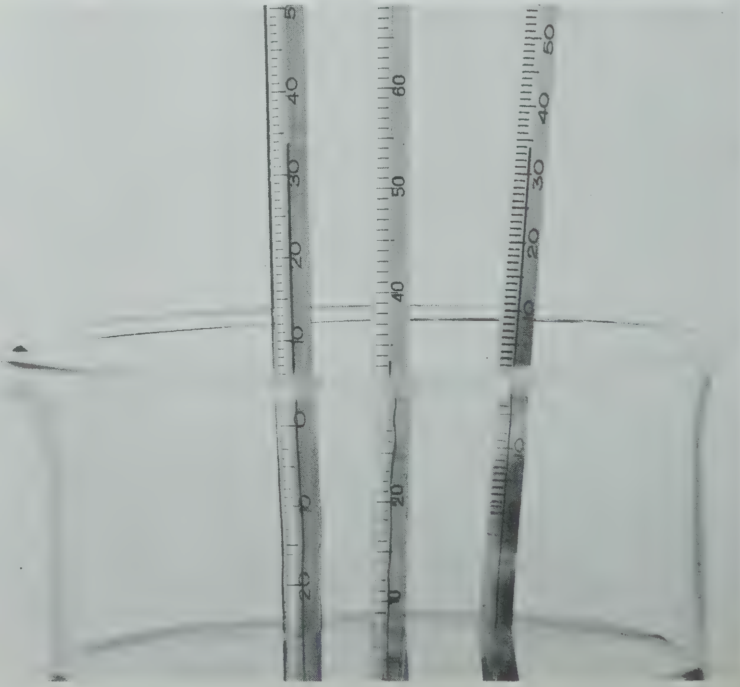
But your reference points have a problem. They aren't fixed. They vary as the hottest and coldest of the water from the faucet varies. And they vary more if water from some other faucet is used.

Your reference points are not accurate because they are hard to reproduce. For instance, if three M-scale thermometers, each made in a different school, were placed in the same pan of water, they would probably give three different temperature readings (figure 13·7a).

Most temperature scales are calibrated according to the melting or boiling points of pure substances. These are usually chosen for reference points because they remain the same under normal conditions. If you put three thermometers, each from a different laboratory, into a pan of water, they would all give the same reading (figure 13·7b).



13·7a



13·7b

The Fahrenheit (far′ən hīt) and Celsius (sel′sē əs) temperature scales are probably the most widely used at this time. Both of these scales today use the boiling and freezing points of pure water as reference points.

Anders Celsius, a Swedish astronomer, first used these reference points in establishing his scale. The boiling point of water is 100° and the freezing point is 0° on the Celsius scale. This scale is used to calibrate laboratory thermometers.

Gabriel Daniel Fahrenheit, a German-born Dutch physicist, started with different reference points when he established his temperature scale (page 336). On the Fahrenheit scale the boiling point of water is 212° and the freezing point is 32°.

The Celsius scale is divided into 100 equal sections or degrees between 0 and 100. Temperatures above 100°C and below 0°C are measured by adding more Celsius degrees to the thermometer.

The Fahrenheit thermometer is divided into 180 equal sections between 32 and 212. Temperatures above 212°F and below 32°F are measured by adding Fahrenheit degrees to the thermometer.

The enlarged thermometer in figure 13·8 has a Celsius scale on one side and a Fahrenheit scale on the other. You can change from one scale to the other by laying a piece of paper across it and reading from one scale to the other.

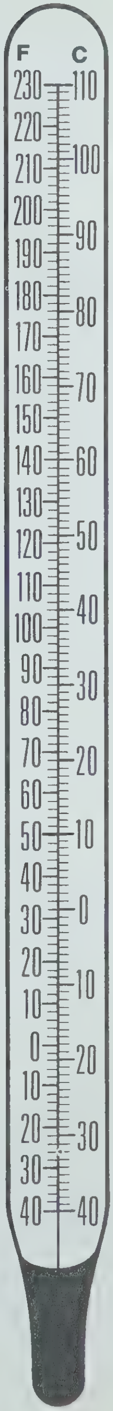
If you don't have such a table handy, you can change from Celsius to Fahrenheit by using an equation:

$$^\circ\text{F} = 32 + 1.8^\circ\text{C} \text{ or } ^\circ\text{C} = \frac{^\circ\text{F} - 32}{1.8}$$

The number 32 appears in each equation because the freezing point of water is 32°F and 0°C.

TEST YOURSELF

1. *What are the reference points of the thermometers we use? Give them in degrees on the Fahrenheit and Celsius scales.*
2. *Why are the melting points and boiling points of pure substances used as the reference points on standard thermometers?*
3. *Convert the following temperatures to °F: 37°C, 20°C, 70°C, −40°C.*
4. *Convert the following temperatures to °C: 85°F, 110°F, 20°F, 0°F.*



13·8

Thermometers and How They Got That Way

The history of temperature measurement

Before you decide what to wear in the morning perhaps you look at an outdoor thermometer or listen to the weather report to learn the temperature. When a chef cooks a roast beef, he may stick a meat thermometer into it to tell him when it's done. You check your body temperature with a thermometer to find out whether you have a fever. Reading a household thermometer today is as easy as telling time. But before the mid-seventeenth century, no instrument existed to measure temperature.

Around 1630 Galileo (gal′ə lē′ō), the Italian scientist, developed the first thermometer, a simple gas one. It was a glass bulb attached to a narrow tube. The other end of the tube was immersed in colored liquid. A change in the temperature of the air in the bulb caused a change in the height of the liquid in the tube. However, this gas thermometer could not measure temperature accurately.

Later Galileo made an alcohol thermometer which was not much better. The height of alcohol in a very thin tube rose or fell as the temperature of the alcohol in the bulb of the thermometer changed.

Galileo's thermometers all suffered from the same serious problem. They did not have reference points. Galileo measured a degree on his scale by determining the change in the height of the alcohol in the tube equal to 1/1000 of the volume of alcohol. That was a pretty tricky thing to do accurately. Most of Galileo's thermometers were made of intricate hand-blown glass (figure 13·10) and no two contained the same volume of alcohol or had the same length tube.

A Galileo thermometer was better than guessing at temperature by the sensation of hot and cold. Galileo's thermometers made the measurement of temperature possible. But they did not make it accurate.

Sir Isaac Newton—the Englishman who legend says was hit on the head with the apple—got into the act in 1701. He came up with the idea that reference points would be handy on a thermometer. He saw the need for some standard with which to compare the increase and decrease in the sensation of hot and cold.

13·9 Spiral thermometer made of Florentine glass.

13·10 Thermometers made for members of a Florentine institution for experimental science in the 17th century. The long tubes were meant to increase accuracy.

13·11 Newton's scale of temperature measurement.

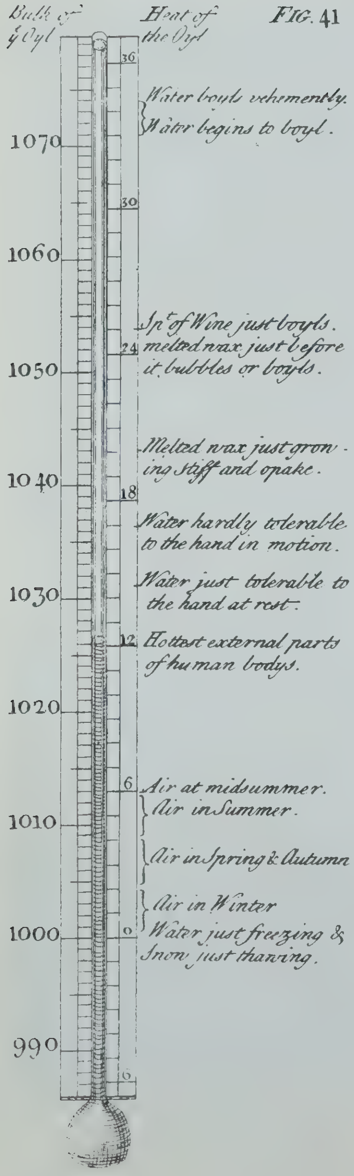


FIG. 41
Bulk of ÿ Oyl
Heat of the Oyl
36
Water boyls vehemently.
Water begins to boyl.
1070
30
1060
Spt of Wine just boyls.
24
melted wax just before it bubbles or boyls.
1050
Melted wax just growing stiff and opake.
1040
18
Water hardly tolerable to the hand in motion.
Water just tolerable to the hand at rest.
1030
12
Hottest external parts of human bodys.
1020
6
Air at midsummer.
Air in Summer.
1010
Air in Spring & Autumn
Air in Winter
0
Water just freezing & Snow just thawing.
1000
990
6

Newton suggested calibrating an alcohol thermometer with the freezing point of water as the first reference point. Newton chose this reference point because he assumed from his observations that the temperature of freezing water is always the same. He also assumed that the temperature of the human body is always the same, so he chose that as his second reference point. Newton divided the space between the two reference points into twelve equal degrees.

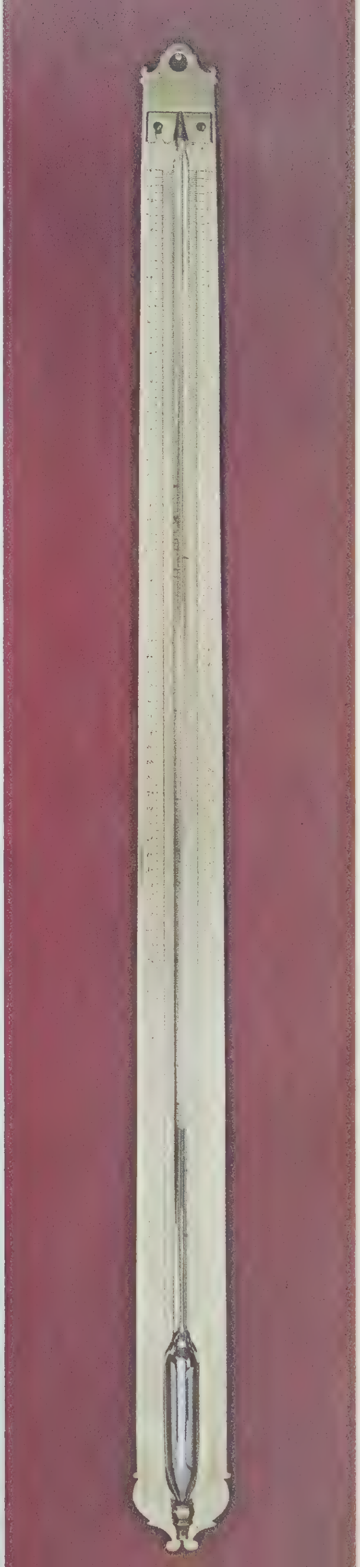
Thirteen years later, Gabriel Daniel Fahrenheit improved on Newton's thermometer. He found a way to purify mercury so he could use it to measure temperature. He also developed his own temperature measurement scale. For his zero point, Fahrenheit chose the lowest temperature he could produce by mixing salt and ice water. That is, he chose the lowest height of the mercury column he could get by immersing his thermometer in various combinations of salt and ice water. For his upper reference point he used the temperature of the human body, as Newton had.

Fahrenheit also divided the distance the column of mercury rose between his two reference points into 12 equal parts. But for convenience, he then subdivided each of the 12 parts into eight sections. (He probably chose eight because you can get eight equal parts easily by dividing each section in half three times in a row.) That gave him 96 equal steps or degrees. Since body temperature is the top reference point, it's 96° on this scale. And the melting point of ice, Newton's bottom reference point, turned out to be 32° on this scale.

Fahrenheit then added sections of the same size to the top of his scale and tried to measure the boiling point of water. When he found that on his scale the boiling point of water was not a whole number, he decided to make some adjustments. So Fahrenheit called the boiling point of water 212° and divided his scale into 180 equal parts between that and the freezing point of water. This changed the scale slightly so that body temperature now measures 98.6° on the Fahrenheit scale instead of 96°.

Unfortunately Fahrenheit chose very poor reference points for his scale. Body temperature changes from hour to hour with exercise, after eating, and so on. It varies with state of health and time of day and from person to person. Fahrenheit's zero point is no better. Different mixtures of ice water and salt can have different temperatures. And Fahrenheit did not specify the exact mixture of ice water and salt to be used. In addition, the temperature of the mixture changes as the ice melts. Therefore, the Fahrenheit thermometers we use today are calibrated according to the freezing and boiling points of pure water.

Twenty-eight years later, Anders Celsius proposed his temperature scale. He used the freezing and boiling points of pure water as reference points. Originally Celsius set the freezing point at 100° and the boiling point at 0°. But he reversed them one year later. Celsius divided his scale into 100 equal parts, or degrees. It was called the centigrade or 100-step scale until the middle of the twentieth century. To honor Celsius for his work, the ninth General Conference on Weights and Measures gave his name to the scale in 1948.



13·12 Early Fahrenheit thermometer

Temperature can be measured by means other than the expansion of a substance

Is There Another Way?

You can't take the temperature of a smokestack with a mercury thermometer. Even if the temperature of the smoke inside the stack could be measured by the expansion of mercury, who'd want to take the thermometer into the smoke-filled stack to get a reading? Yet it's important to know the temperature inside the stack because the pollution-control equipment at the top of the stack works best within a certain range of temperatures. And no company wants to pay fines for unnecessary pollution or have expensive equipment ruined by smoke that is too hot.

To take the temperature of a smokestack you need a different kind of temperature-measurement device. The one that is the most likely to be used is called a *thermocouple*.

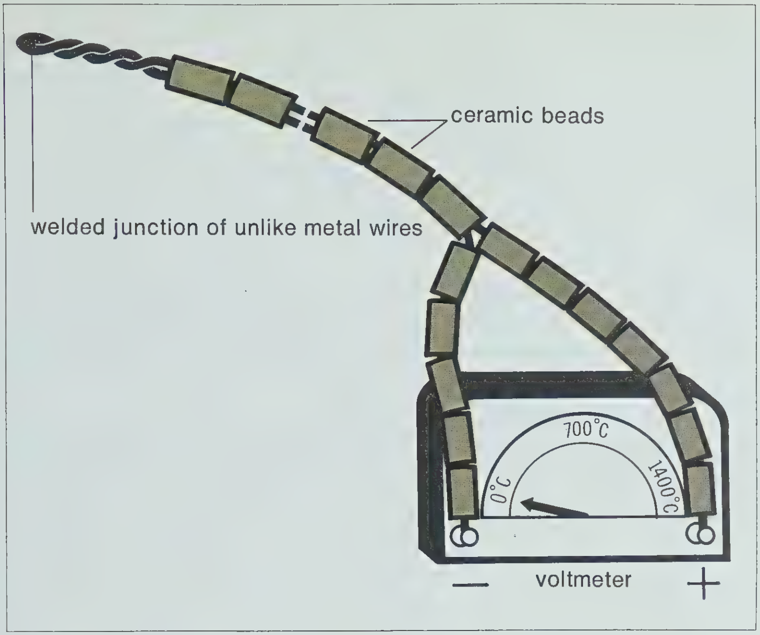
The thermocouple uses electric current to measure temperature. It works because a small voltage is produced when unlike metals touch. This voltage changes as the temperature at the point of contact of the metals changes. For instance, a junction of iron and constantan (a copper-nickel mixture) produces lower voltage at room temperature than it produces in a heated oven. Other pairs of metals do exactly the same thing. So thermocouples are made of those pairs of metals that will produce the largest possible voltage when the junction is heated.

In the thermocouple, wires of each of the metals being used are welded together. The junction of these wires is placed in the area where the temperature is to be measured. Since it is the voltage that changes as temperature changes, the far ends of the wires are connected to a sensitive voltmeter (figure 13·14). The scale of the voltmeter is usually calibrated to give the temperature of the metal junction within the temperature range in which the junction produces a measurable voltage (Table 2).

The voltmeter can be a long distance away from the spot where the junction is measuring the temperature. So you can measure the temperature inside a smokestack while you are on the ground or in the factory below it.

Thermocouples are not practical for measuring the temperatures inside plastic-molding machines. Molded plastics do not come out

13·13



13·14 Thermocouple attached to voltmeter calibrated in °C.

well if the molding machines are not working at the proper temperature. The measurement of that temperature must be extremely accurate. To keep the machines working at the proper temperature, you must be able to measure the temperature accurately at all times. One instrument that can be used to monitor the temperature inside a machine with extreme accuracy is a *resistance thermometer*.

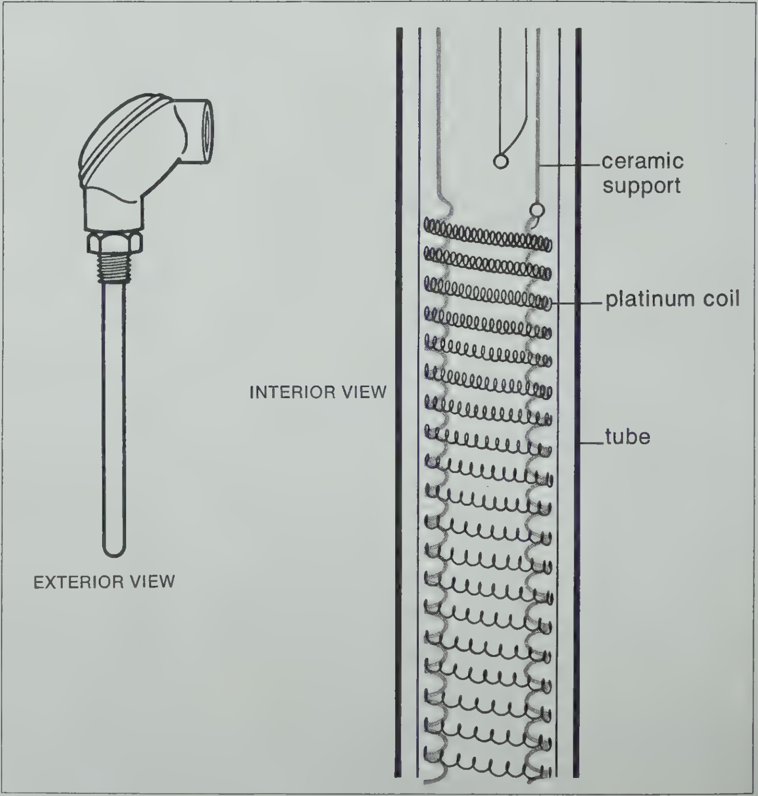
Table 2

Temperature Ranges of Thermocouples

Metals or alloys welded together		Temperature
First wire	Second wire	range, °C
90% Platinum 10% Rhodium	Platinum	0 to 1450
Chromel-P 90% Nickel 10% Chromium	Alumel 94% Nickel 2% Aluminum 3% Chromium 1% Silicon	−200 to 1100
Iron	Constantan 55% Copper 45% Nickel	−200 to 750
Copper	Constantan	−200 to 350
Chromel-P	Constantan	−100 to 1000

The resistance thermometer, like the thermocouple, uses electric current to measure temperature. It makes use of the fact that the resistance of metals to electric current changes as the temperature of the metal changes.

Resistance thermometers are usually made out of platinum wire (figure 13·15). Platinum has a high electrical resistance and a high melting point (1773.5°C or 3224.3°F). These properties make it useful for measuring high temperatures. In addition, the platinum does not wear away very easily. For this reason it can be used to measure the temperature of chemical reactions in which less hardy temperature-measurement devices might be destroyed.



13·15 Platinum resistance thermometer

In the resistance thermometer, a platinum wire is coiled around a supporting material. This supporting material must have a melting point at least as high as that of the platinum.

The support keeps the platinum wire from being strained while it expands and contracts as its temperature rises and falls. Such strain might affect the resistance of the platinum. Any change in electrical resistance of the supported platinum coil must be a direct result of the temperature change for the reading to be accurate. When the platinum coil is going to be used in an area where the platinum could be harmed, the coil and support are sealed in a tube.

In the simplest resistance-thermometer circuit, the temperature-sensitive coil connects in a series circuit with a constant voltage source and a microammeter (a meter that measures one millionth of an amp).

The electrical resistance of the coil increases as the temperature of the area around it rises. As a result, the current through the circuit decreases. This small change in the current through the circuit can be read on the microammeter. In most resistance-thermometer circuits, the microammeter is calibrated so that it gives the temperature of the coil rather than the current through the coil.

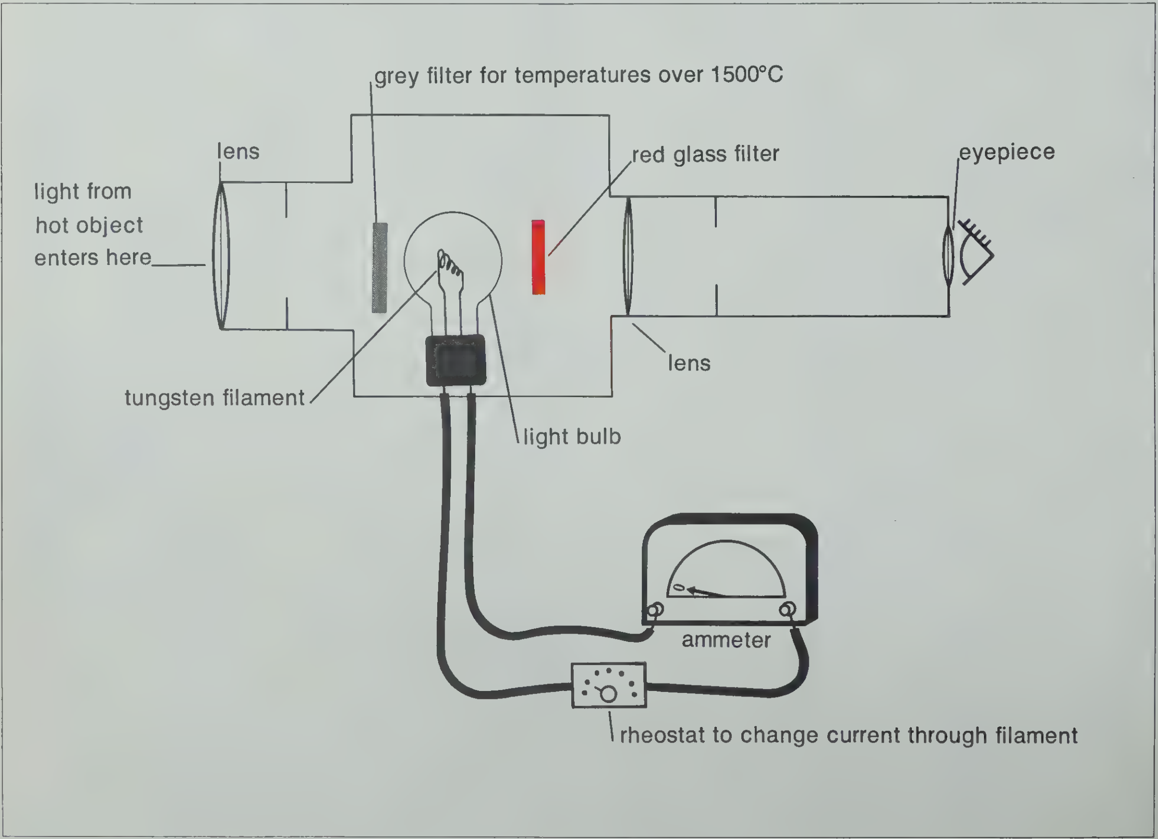
Resistance thermometers can be used to measure the temperatures inside a series of refrigerators or freezers in a frozen-food factory as well as the temperatures inside smokestacks and plastic-molding machines. A platinum resistance thermometer will accurately measure temperatures as low as −260°C. For this reason, it is also very useful in research carried out at extremely low temperatures.

Platinum resistance thermometers cannot be used to measure the temperature of things that are hotter than the temperature at which platinum melts. Neither can thermocouples. But it is sometimes necessary to measure the temperature of things that are that hot. For example, the temperature inside the ovens in which ceramics are hardened and glazed must be measured to be controlled. It is also necessary to measure the very high temperatures around a spacecraft reentering the earth's atmosphere. In this way, engineers get the information to improve their design for the protective covering of a spacecraft.

13·16

One instrument that can be used to measure extremely high temperatures without touching the hot object is an *optical pyrometer.* The optical pyrometer is based on the fact that the brightness of light given off by a hot object changes as the temperature of the object changes. The most common optical pyrometer is the disappearing filament type (figure 13·17). To measure temperature with a disappearing filament optical pyrometer, you look through a lens and a red glass filter at the hot object whose temperature you are trying to measure.

13·17 Optical pyrometer


grey filter for temperatures over 1500°C
lens
red glass filter
eyepiece
light from hot object enters here
lens
tungsten filament
light bulb
ammeter
rheostat to change current through filament

A light bulb with a tungsten filament is a necessary part of the pyrometer. It is located between the filter and the outside of the pyrometer. When you look through the pyrometer, you see the bulb filament against the hot object whose temperature you are measuring. The resistance through the circuit containing the light bulb can be varied to change the current through the filament. A change in resistance will make the bulb filament dimmer or brighter. The resistance is varied until the brightness of the filament blends in with the brightness of the other hot object.

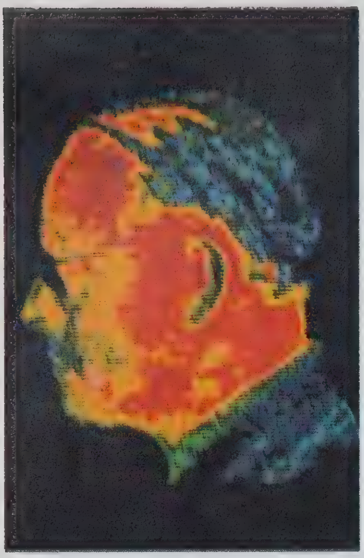
The current through the filament at this point is related to the intensity of the light given off by the hot object. The current registers on a meter that reads in thousandths of an amp. The pyrometer manufacturer supplies a conversion table. You can use the current reading and the table to find the temperature of the hot object.

The optical pyrometer is not without faults. You cannot use an optical pyrometer to measure temperatures below 500°C to 600°C (around 1000°F). Objects at lower temperatures do not give off enough visible light. And you cannot use an optical pyrometer to measure temperatures accurately. It depends on the ability of the human eye to match brightness.

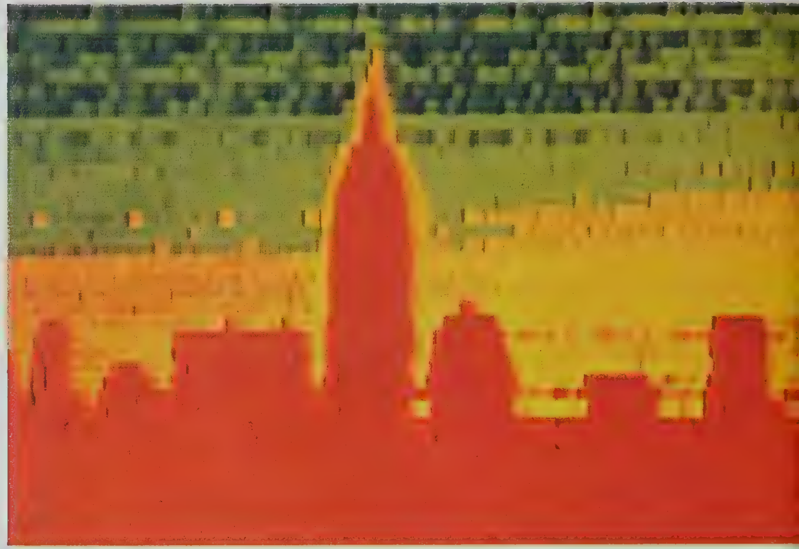
However, you can measure very high temperatures with an optical pyrometer. Filters are placed in front of the pyrometer to measure temperatures above 1500°C. These lower the brightness of the entering light by a known amount. The results are then corrected to make up for the brightness held back by the filters. With these filters, pyrometers can be used to measure the surface temperatures of the stars. And they are often used in the study of the burning and explosion of gases for rocket-engine design.

Pyrometers are used to measure the temperature of objects hot enough to give off light that is visible to the human eye. Another temperature-measurement device which depends on light, measures light which is not visible to the human eye. That device is the *thermograph*. The thermograph measures the amount of light an object gives off when that object is in the temperature range that can be measured by a mercury thermometer.

13·18 The view through the eyepiece of an optical pyrometer. In the top circle, the filament is cooler than the hot object. In the center, the filament is hotter than the hot object. On the bottom the filament is at the same temperature as the hot object.



13•19a Thermogram of person's face. Which areas do you think are warmest and coolest?



13•19b Thermogram of city skyline. Notice the range in temperatures.

The thermograph is used to take a photograph called a *thermogram*. The film used in the thermograph is sensitive to light that is not visible to the human eye. The thermograph can be adjusted so that when the film is developed, it will vary from black to white over a 0.55°C (1°F) difference in temperature.

When it is used with color filters and color film, this device will produce thermograms in which each color represents a different temperature range (figure 13•19). These color thermograms can also show temperature differences of less than 1°C.

The fact that thermographs can detect such small temperature differences makes them very useful in factories. Some industries use thermograms to find weak spots in metal and plastic objects.

The surface of the object above a flaw usually differs slightly in temperature from the rest of the surface. The thermograph's main advantage is that it does not damage the object being tested. For instance, a steel beam can be checked for flaws without being sawed into pieces. And if no flaws are found, the beam can be sold and used.

The thermograph is also very valuable in detecting certain kinds of human diseases. Doctors use it to spot variations in skin temperature. A higher-than-normal temperature might mean cancer in the tissue below an area of the skin. A lower temperature might point out poor flow of blood in the area being studied. Such findings help doctors discover illnesses in the early stages, while they may be curable.

ON YOUR OWN

Freezing point of water

You can use these materials to find why thermometers are calibrated according to the freezing point of pure water:

4 water glasses (all alike)
1 small pan
1 1-pint jar with lid to fit
4 paper napkins
Rubber bands
Salt
Water
Freezing compartment of
  refrigerator or freezer

Put about 3 glassfuls of water into the pan. Boil the water on a stove for two minutes. Fill one glass 3/4-full of the boiled water and label the glass. Put the pan of water aside to cool.

Fill the second glass 3/4-full of tap water and label it. Then put a tablespoon of salt into the third glass. Fill it 3/4-full of tap water and stir to dissolve the salt. Label the glass.

Put a glassful of the cool boiled water into the jar. Place the lid on the jar and tighten it. Shake the jar hard to dissolve some air in the boiled water. Pour that water in the last glass so that it is 3/4-full.

When all of the glasses of water are at room temperature, cover the top of each glass with a napkin. Put a rubber band around the napkin to keep it on. Then place the glasses in a freezer. Open the freezer at 10-minute intervals. Note the order in which the glasses of water freeze.

An unusual thermometer you can use

You cannot take the temperature of a block of iron by putting a thermometer on top of it. Or can you? Will you be measuring the temperature of the block or of the surrounding air? It depends on what kind of thermometer you have.

One kind of thermometer, or temperature measurer, can be painted onto almost any object. It is called *liquid crystal thermal paint*. This paint changes color with changes in temperature (figure 13·20). It can show the range of different temperatures (temperature gradients) across the surface of an object.

Suppose you put a metal ladle, a wooden spoon, and a glass stirrer into a pot of hot soup. If all three have been painted with liquid crystal paint, after a short while they will look like the ones in figure 13·21.

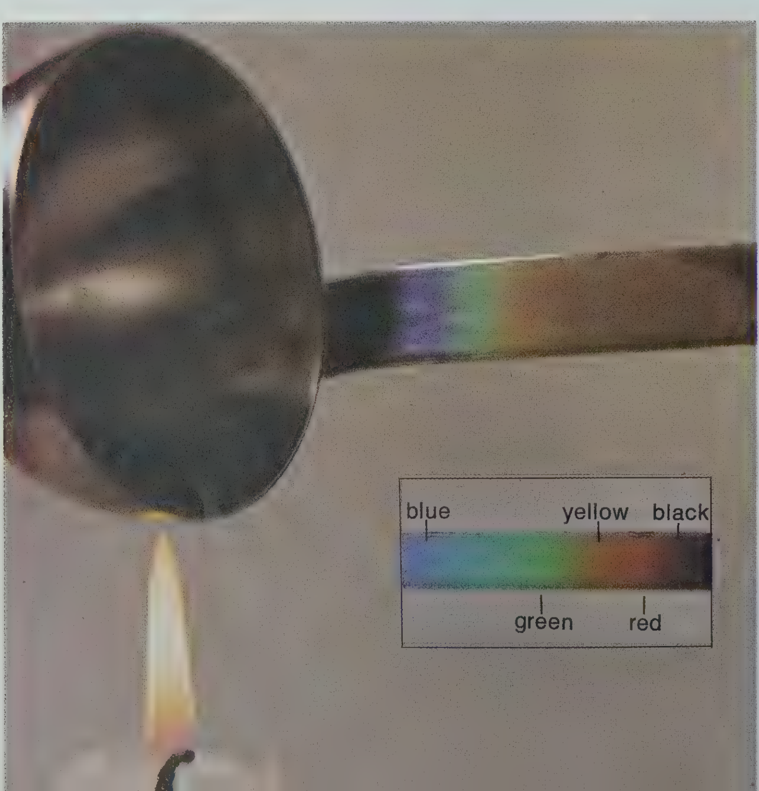
How did the temperature of the handle of the ladle change? What happened to the wooden spoon in the same soup? Did the glass rod act like the spoon or like the ladle or still differently?

From what you have seen, you may conclude that heat passes through substances much as electricity does. Some substances, like the metal ladle, conduct heat rapidly. Others, like the glass and wood, conduct heat so slowly that they do not seem to conduct heat at all sometimes.

The photographs in figure 13·22 show how heat is conducted through some common materials.

TEST YOURSELF

1. *Why are the handles of pans often made of wood or plastic?*
2. *Why is liquid crystal paint used to show how heat moves across the surface of an object?*



13·20 The temperature ranges shown are: below 30°C—black, 30°C to 31.5°C—red, 31.5°C to 32.5°C—yellowish, 32.5°C to 36°C—green, and over 36°C—blue.

13·21a

13·21b

13·22a

13·22b

13·22c

Chapter 14: Supplying Heat

14

Would you rather get the bill for heating a small house or for heating a large school? The furnace in the house and the one in the school each keep the rooms at about the same temperature. But the school has many more rooms. So the school's furnace must supply more heat. As a result, it costs more to heat the school.

Suppose two pots of soup, one small and one huge, are sitting over the same size flame on a gas stove. It's obvious which pot will boil first.

There is another thing about supplying heat—in the scientific sense, that is. It can be done in several ways. For example, the flame on a gas stove supplies heat directly to a pan. The pan then supplies heat directly to the soup in it.

On the other hand, furnaces do not supply heat directly to things and people in a house or a school. That could get rather uncomfortable. One kind of furnace supplies heat directly to air being forced through it. Once the warm air enters the building, it moves around, spreading its warmth.

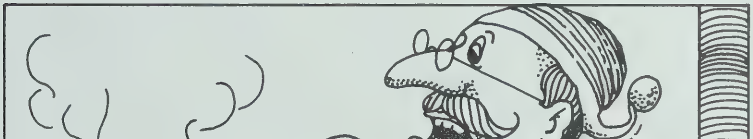
Another kind of furnace supplies heat directly to water pipes. The pipes then supply heat to the water flowing through them. From there, the heated water is forced through the pipes into radiators in the different rooms. The radiators supply heat to the air. Again, as the warm air circulates, it spreads its warmth.

The last chapter was about temperature as a measurement of how hot or cold something is. This chapter's about measuring heat, for example, how much heat is supplied to give something a certain temperature.

Take another look at that pot of boiling soup. As long as there is a flame under it, heat will be supplied to it. But something different happens when you place that pot on a cool surface. Then the *pot* supplies heat to the surface until both are the same temperature. However, it is hard to notice that moment when the pot and the surface it is on are at the same temperature.

The pot is also in contact with the air. So it is supplying heat to the air around it too. After a while the pot and the surface under it will end up being the same temperature as the air in the room.

The temperatures of liquids that are mixed balance out in a similar way. When milk that has been in the refrigerator is added to hot chocolate, the milk becomes warmer and the chocolate cooler. Both end up at the same temperature. The same sort of thing happens when you adjust the temperature of the bath water. You add hot water if your bath is too cool. Then the hot water cools down and the cool water warms up, until you're left with water at one temperature. And this happens in a way that is easy to study.



14·1

ON YOUR OWN

Heat and temperature.

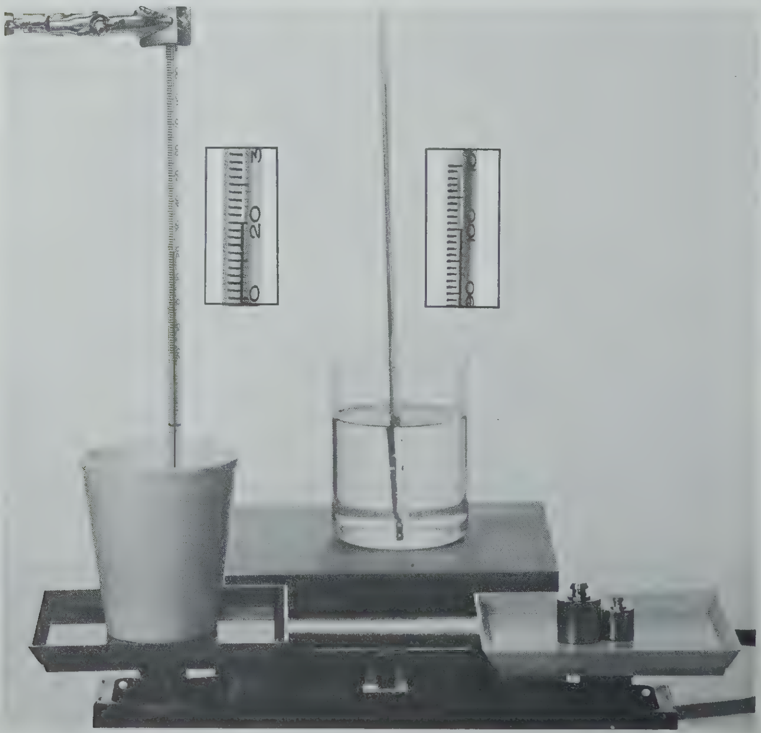
You will need a small saucepan, water, a glass, a thermometer, and a source of heat.

Pour 1 glass of water into the saucepan. Measure the temperature of the water. Heat the saucepan of water for exactly 5 minutes. Measure the temperature of the water again. How much did it change?

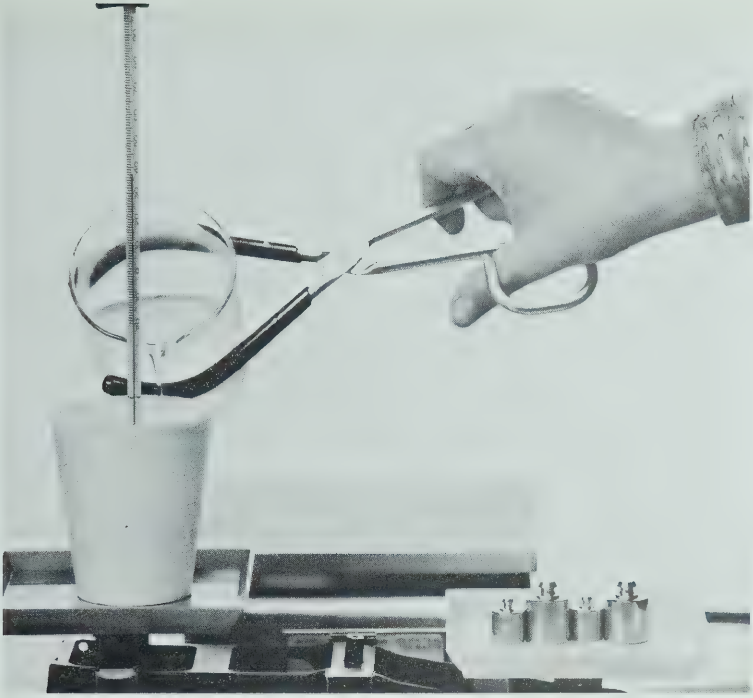
Keep the heat source exactly the same. Repeat the activity with 2 glasses and with 3 glasses of water. Compare the change in water temperature for each mass of water. Did the heat source supply the same amount of heat to the water during all the activities?

In figure 14·2, 70 grams of water at 100°C are being added to 70 grams of water at 20°C. The water at 20°C is about room temperature. Notice that the temperature of the 20°C water rises and the temperature of the 100°C water falls until all the water in the cup reaches the same temperature (figure 14·2c). At this point no portion of water is supplying heat to the other. The temperature at which this happens is called *equilibrium* temperature.

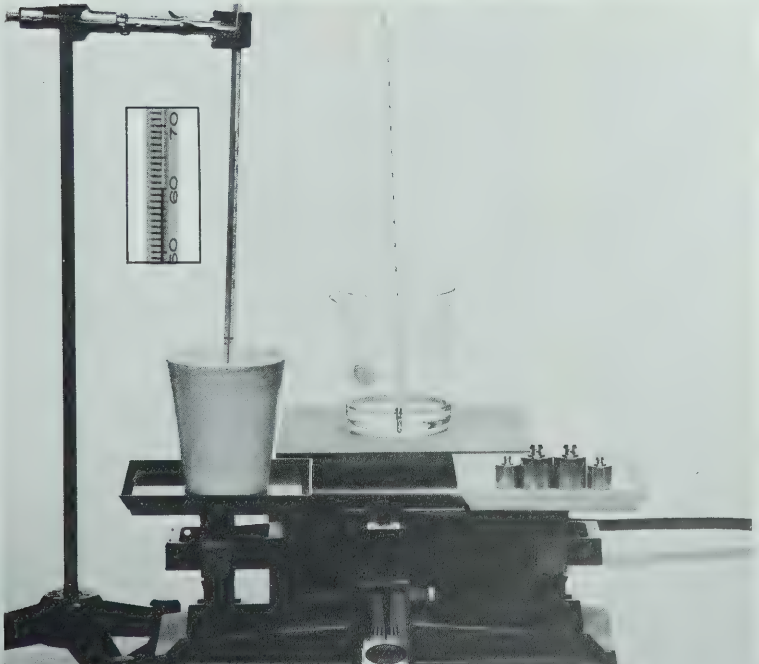
Every time two materials, each at a different temperature, are mixed, the mixture will reach an equilibrium temperature. That is, one will become cooler and the other will become warmer until both are at the same temperature.



14·2a Notice that the room temperature water is in a styrofoam cup. Styrofoam is a very good insulator. It keeps the water in the cup from supplying heat to the air or the balance. It also keeps the water from being supplied with any heat that might be radiated by the hotplate behind the balance.



14•2b Water at 100°C is being added to the 70 grams of water at 20°C. The temperature of the water in the styrofoam cup is rising.



14•2c Notice that the styrofoam cup now contains 140 grams of water at 60°C. The styrofoam cup is still acting as an insulator. It keeps the water inside from supplying heat to the air or the balance.

How much heat was supplied?

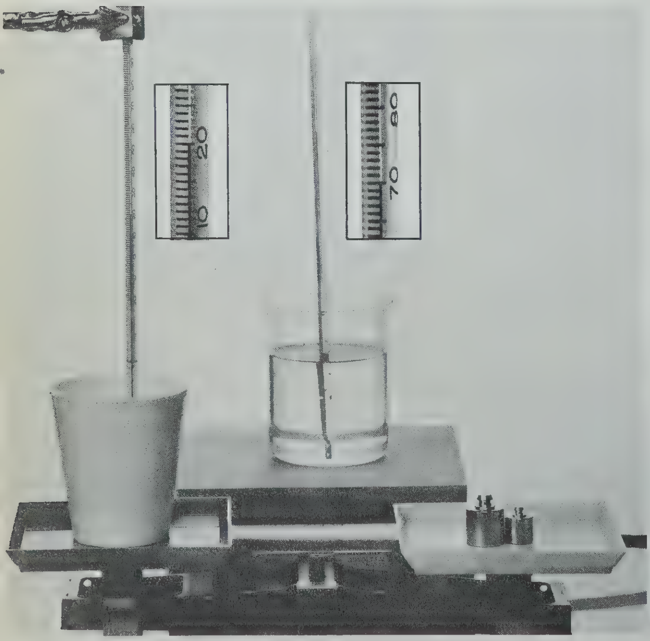
In the last section hot water was added to cool water. In this way, the hot water was supplying heat to the cool water until the combination reached equilibrium temperature. The equilibrium temperature was neatly in the middle of the two starting temperatures.

In figure 14·3, 70 grams of hot water is again being used to supply heat to cool water. But this time the temperature of the hot water is different than it was before. Everything else in the experiment is the same.

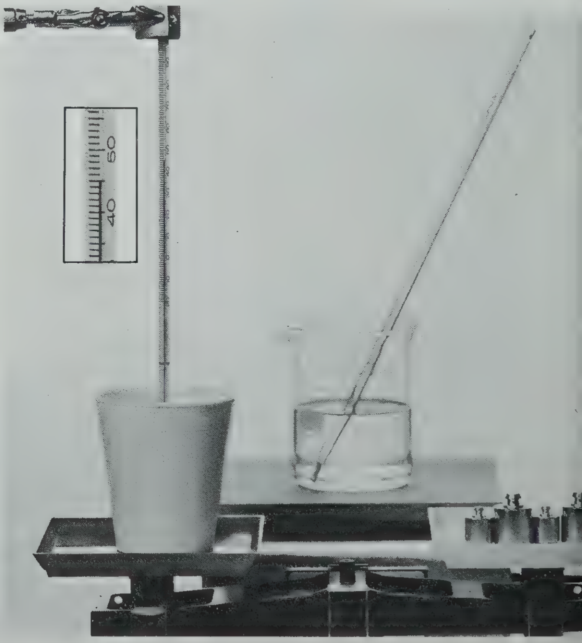
The 70 grams of 70°C water supply heat to the 70 grams of 20°C water until they have reached equilibrium temperature. The equilibrium temperature is again halfway between the two starting temperatures. But in this experiment, equilibrium temperature isn't 60°C. It's 45°C.

In both experiments the hot water had the same mass. (Mass is a measure of the quantity of matter.) And it was added to the same mass of cool water at the same temperature. Only the temperature of the hot water was different. And the final temperature of the mixture was different.

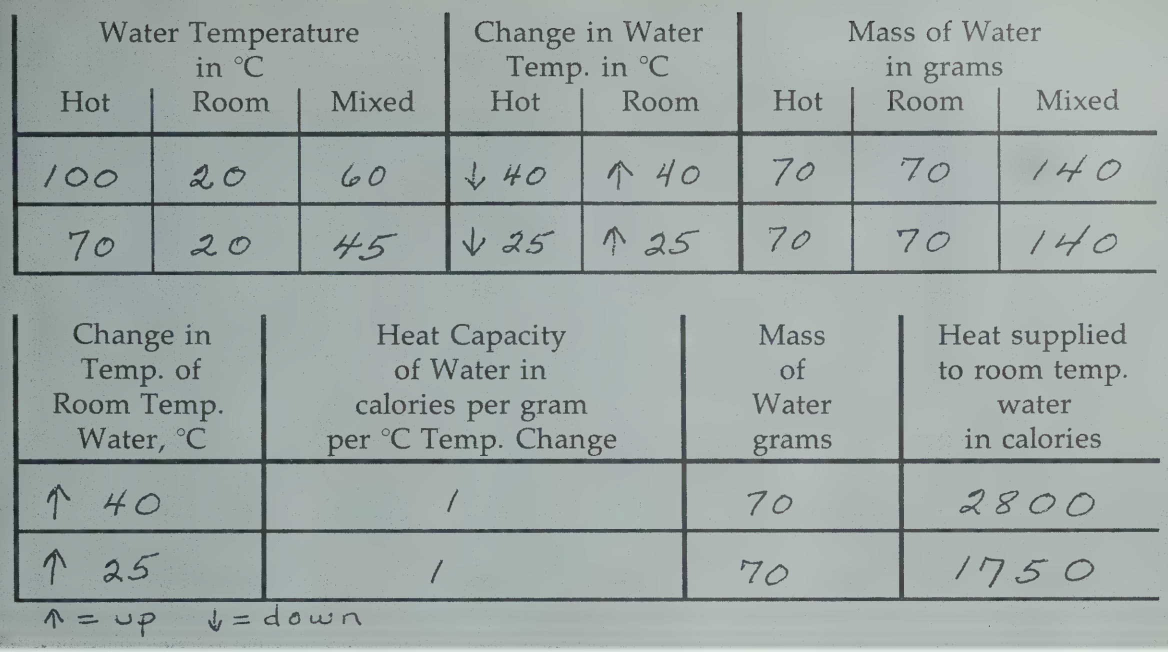
The water at 100°C supplied more heat to the cool water than did the water at 70°C. But how much more heat did it supply? And how much heat would 70 grams of water of a different temperature supply to the cool water?



14·3a



14·3b



Water Temperature in °C			Change in Water Temp. in °C		Mass of Water in grams		
Hot	Room	Mixed	Hot	Room	Hot	Room	Mixed
100	20	60	↓ 40	↑ 40	70	70	140
70	20	45	↓ 25	↑ 25	70	70	140

Change in Temp. of Room Temp. Water, °C	Heat Capacity of Water in calories per gram per °C Temp. Change	Mass of Water grams	Heat supplied to room temp. water in calories
↑ 40	1	70	2800
↑ 25	1	70	1750

↑ = up ↓ = down

14·4 Laboratory notebook page with heat-experiment data.

A way to measure the amount of heat that each cup of hot water supplied to the cool water is needed in order to answer these questions.

You must take into account the mass of the water to which heat has been supplied. And you must take into account the number of degrees that water rose in temperature due to the supply of heat.

There is a unit of heat which makes these measurements possible. It's called a *calorie*. A calorie is defined as the amount of heat that must be supplied in order to raise the temperature of 1 gram of water 1°C. It's an internationally accepted unit.

The notebook in figure 14·4 shows how many calories of heat were supplied to the cool water by each cup of hot water. The water temperature in the first experiment rose 40°C. It takes 1 calorie to raise the temperature of 1 gram of water 1°C. Thus it takes 70 calories to raise the temperature of 70 grams of water 1°C. The water temperature rose 40°C. So it must have taken 2800 calories to raise the temperature of the cool water (70 calories per degree × 40° = 2800 calories). Where did those calories come from? Notice what happened to the temperature of the hot water added in this experiment.

In the second experiment, the temperature of 70 grams of cool water rose only 25°C after the water at 70°C was added. At 70 calories per degree, a total of 1750 calories (70 calories per degree × 25 degrees) must have been supplied by the hot water.

TEST YOURSELF

1. *What does the term "equilibrium temperature" mean?*
2. *What is a calorie?*
3. *Suppose 70 grams of 90°C water is added to 70 grams of 20°C water. The temperature of the cool water will rise 35°C. How many calories will have been supplied to the cool water?*
4. *How many calories must be supplied to 20 grams of water to raise the water temperature by 7°C?*
5. *How much heat must be supplied when the temperature of 150 grams of water rises from 42°C to 54°C?*

Food supplies the heat to run the human "engine"

Calories You Eat

14·5

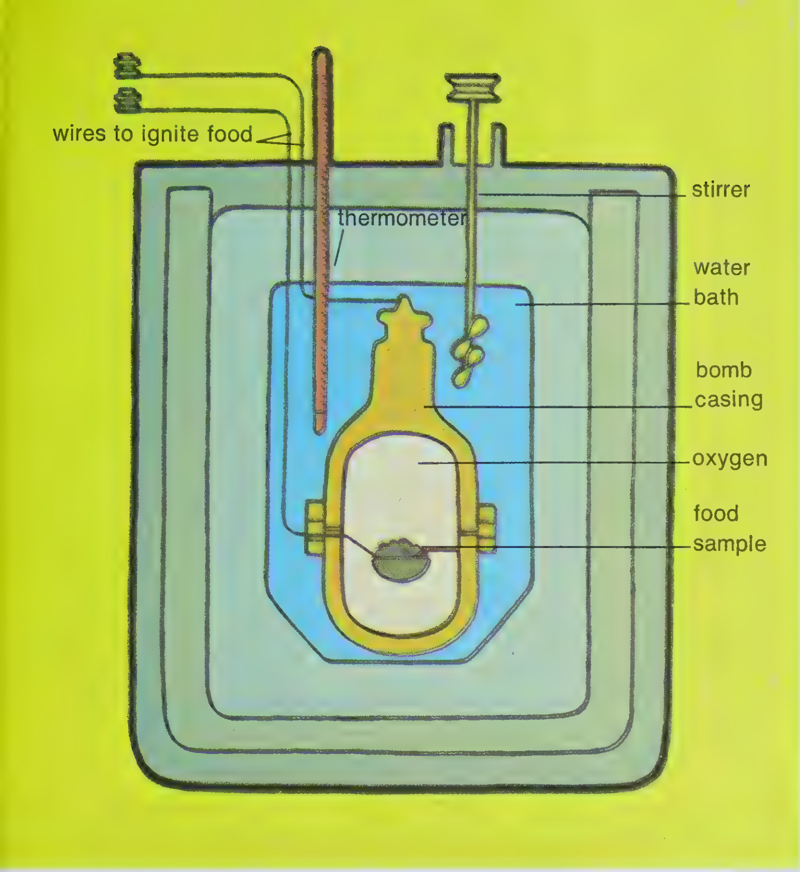
Have you ever tried to lose weight by going on a diet? If so, you may have studied a Calorie chart, which gives the Calorie values of various kinds of food. You might use such a chart as a guide to which foods to avoid: those having a high Calorie value. But do you know what a Calorie is? how it differs from a calorie? why foods that are high in Calories tend to be "fattening"? why if you diet, or cut Calories, you may find that you tire rather easily?

The human body works as a kind of heat engine. The food you eat provides its fuel. Your body "burns" food to produce the energy you need.

The greatest part of this energy goes just to keep you alive. It regulates body temperature, circulates blood, and keeps other systems of your body working. You use the next largest part of the energy supplied by food for all kinds of physical activity—anything more than resting in bed. And the smallest part of the energy goes to digest and release the energy from food. Any part of the food that is not needed as energy is stored in the body.

Scientists measure the energy content of food in terms of the heat given off when it burns. Food Calories (with a capital C) are really *kilo*calories. That is, one food Calorie is the same as 1000 of the calories you studied about in the last section. Calorie charts say a slice of bread has a value of 60 Calories. If the slice of bread burns, it can raise the temperature of 60,000 grams of water 1°C.

The amount of heat given off by a food when it burns can be measured in a *bomb calorimeter*. The bomb calorimeter (figure 14·6) consists of an insulated container of water and a sealed metal container that looks like a vacuum bottle. The metal container, or bomb, holds the food to be tested and more than enough oxygen to burn the food completely. The bomb sits in a carefully measured amount of water that contains a very accurate thermometer. The heat produced by the burning food sample goes through the walls of the bomb and raises the temperature of the water. A mechanical stirrer in the water keeps the water moving so that equilibrium temperature is reached quickly. You can calculate the energy value or fuel value of the food from the change in the temperature of the water.



14·6 Bomb calorimeter

The energy value of foods that you find on a Calorie counter is based on bomb-calorimeter measurements. The calorimeter measures *all* available energy that can be obtained by burning the food. But your body does not use food so efficiently. Another set of values, based on the human body's use of food energy, is called the *physiological fuel value.*

The physiological fuel values are obtained by making a series of corrections to bomb-calorimeter measurements. These corrections take into account the incomplete burning and incomplete digestion of the foods you eat.

Research scientists have found that a gram of salad oil, or fat, yields 9.45 Calories in a bomb calorimeter. But the same gram of oil supplies only 9 Calories to your body. A gram of carbohydrates, such as sugar, yields 4.10 Calories in a calorimeter but 4 Calories in your body. And a gram of protein—which is found in meat, poultry, and milk—yields 5.65 Calories in a calorimeter but only 4 Calories in your body.

14·7 The amount of fuel burned by the human engine during any activity is measured in Calories per kilogram of body weight per 10 minutes of that activity. The ice skater is using around 2 Calories, the ladder climber around 1.5 Calories, the snowball thrower about 0.5 Calorie, and the bicycle rider about 0.75 Calorie.

Most foods contain all three nutrients—fat, carbohydrate, and protein. For example, 100 grams of whole milk contains 4.9 grams carbohydrate, 3.9 grams fat, 3.5 grams protein, and 87.7 grams water.

To find the energy value of the milk, multiply the amount of each type of nutrient by the physiological fuel value for that nutrient. Thus, the milk contains 4.9 grams times 4 Calories per gram, or 19.6 Calories of carbohydrate; 3.9 grams times 9 Calories per gram, or 35.1 Calories of fat; and 3.5 times 4, or 14 Calories of protein. The total energy value of the milk can be added in the following way: 19.6 Calories + 35.1 Calories + 14.0 Calories = 68.7 Calories.

Now that you've had a snack full of Calories, it's time to return to solid food. So let's get back to the calories with a small *c*.

Table 1

Caloric Values of Favorite Foods

Food - 1 serving	Calories
Apple	70
Apple pie	345
Chocolate cake	445
Chocolate candy bar	150
Chocolate milkshake	405
Cola-type beverage	95
Doughnut	125
Frankfurter on a bun	270
French fries, 10	155
Hamburger on a bun	360
Ice cream, 1/4 pint	145
Milk, whole	160
Pizza, cheese	185
Potato chips, 10	115
Spaghetti, Italian style	436
Waffle	210

ON YOUR OWN

Calories and your weight

You can keep track of the Caloric value of the food you eat and the way you use your Calories with these materials:

1 small spiral notebook
1 Calorie booklet (available at a grocery or book store)

In the notebook, write down everything you do over a 24-hour period. Record each activity and the amount of time you spend at it. For instance, record the number of hours you sleep, eat, sit, walk up or down stairs, and so forth.

On another page of the notebook record everything you eat and drink over the same 24-hour period. Be sure not to miss a single mouthful. Write down the type of food or drink and the exact amount you have consumed, as best you can.

Use the Calorie booklet to find the total Caloric value of the food and drink you have consumed. Then look for the chart that will tell you how many Calories you use for each type of activity. Find how many Calories you used in 24-hours. Compare the two sets of figures.

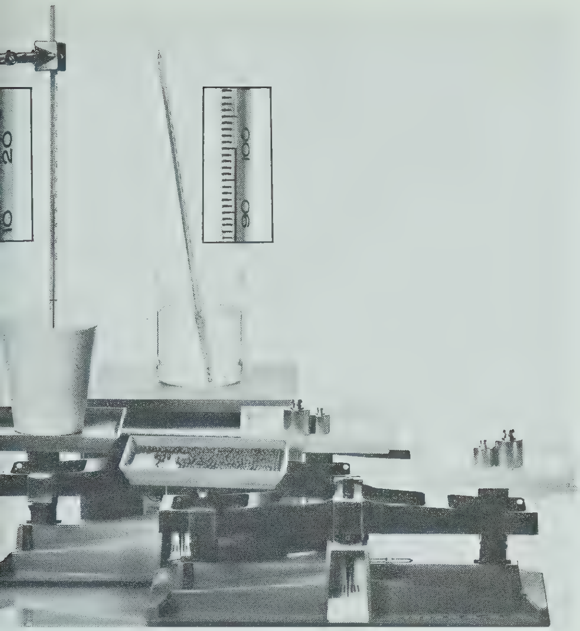
Supplying heat with hot metal

So far only hot water has been used to supply heat to the cool water. And the experiments have all had similar results. When hot water was used to supply heat to an equal mass of cool water, the equilibrium temperature of the mixture was halfway between the two starting temperatures.

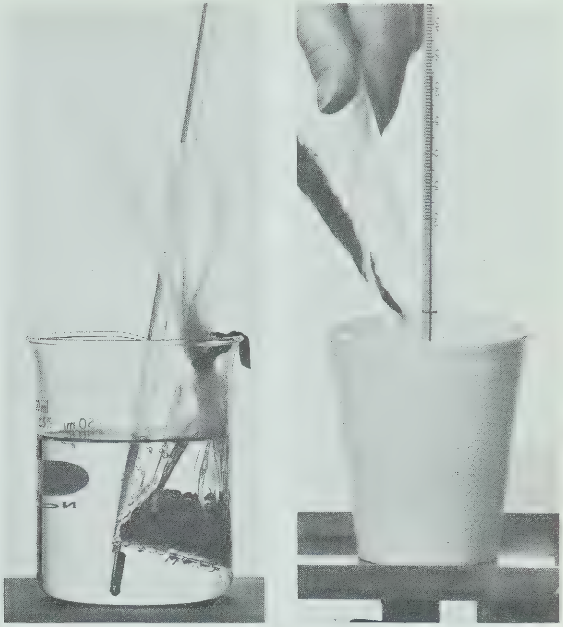
Now let's supply heat to some cool water with pieces of hot metal. In figure 14·8, a 70-gram mass of iron shot, with a temperature of 100°C, is added to 70 grams of 20°C water. The mass and temperature of the hot iron is the same as that of the hot water in figure 14·2. For this reason the results of the experiments will be easy to compare. The same is true for the mass and temperature of the cool water.

The pieces of iron, held in a plastic cooking bag, are heated to 100°C in a cup of boiling water. When the room-temperature metal is first added to the boiling water, the water stops boiling. Its temperature falls as it supplies heat to the pieces of iron.

But the hot plate under the boiling water is supplying heat to the water, the plastic bag, and the iron. So when the water returns to a full boil,



14·8a

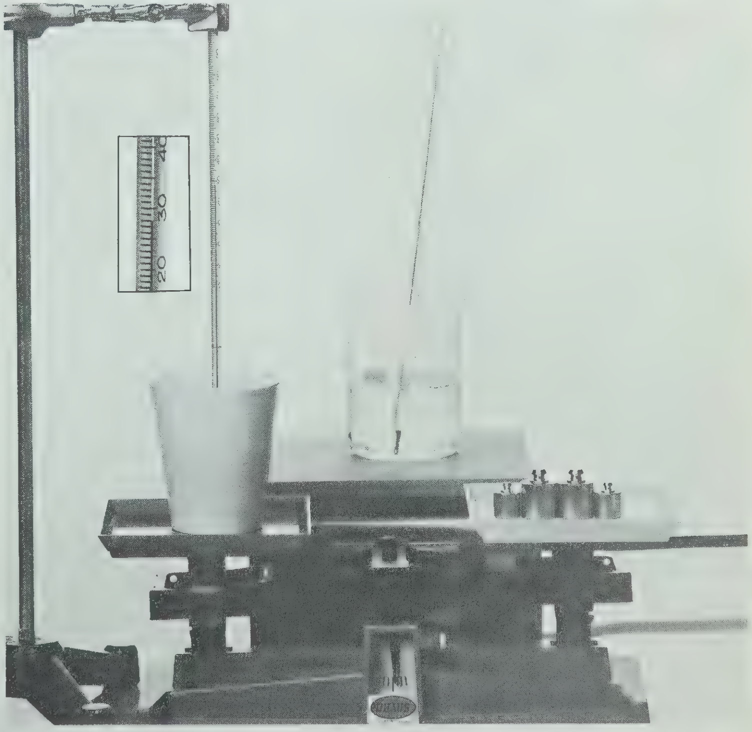


14·8b

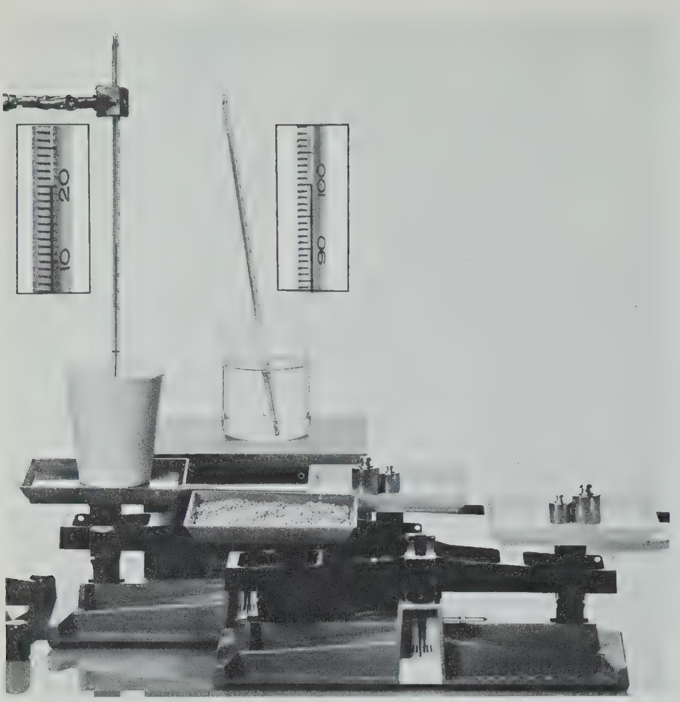
you can assume that the equilibrium temperature of the water and the pieces of iron is 100°C.

Once the iron is at 100°C, the plastic bag is taken from the boiling water. The iron is emptied into the 70 grams of cool water. Notice how much the temperature of the water and of the iron have changed by the time they have reached equilibrium temperature (figure 14·8c).

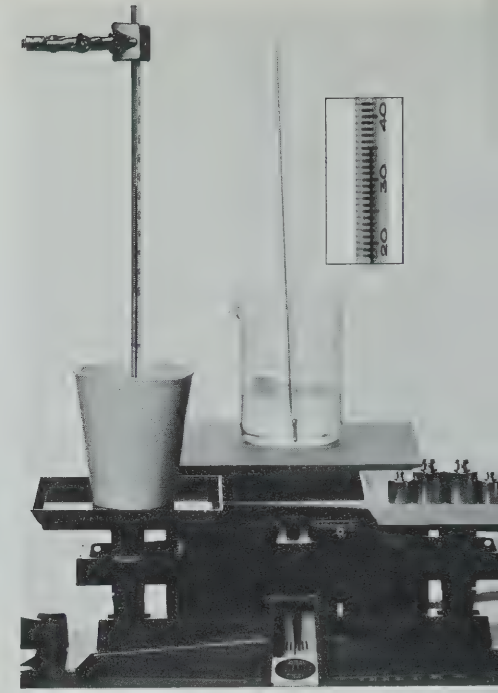
The 70 grams of water started at 20°C. What is its temperature now? The 70 grams of iron started at 100°C. What is its temperature now? Is the equilibrium temperature in the middle of the two starting temperatures? It was when equal masses of water were added to each other.



14·8c



14·9a



14·9b

Figure 14·9 shows heat being supplied to 70 grams of 20°C water by a 70-gram mass of aluminum shot. The aluminum is brought to 100°C in a cup of boiling water before it is added to the water. Again notice the equilibrium temperature of the mixture.

How much did the 70 grams of water rise in temperature? How much did the 70 grams of aluminum fall? How do these results compare with those of the first two experiments that involved mixing of water alone? with the experiment using iron?

There is a striking difference between the change in temperature of the cool water caused by the hot water, by the hot iron, and by the hot aluminum. Other substances show still other changes in temperature when they are used in identical experiments.

The notebook page in figure 14·10 shows data from the above experiments and another experiment in which a 70-gram mass of copper shot was used to supply heat to water. The final temperature column gives the equilibrium temperature of the water and the metal.

The temperature of the 70 grams of 20°C water rose 40°C when 70 grams of 100°C water were added to it. Notice that *none* of the 70-gram masses of metal shot—all 100°C in the beginning—caused the same change in the temperature of the water.

The experiment in figure 14·2 showed that 70 grams of water at 100°C added 2800 calories of heat to the cool water. Before going any further, let's calculate how much heat the 70 grams of iron supplied to the same amount of cool water.

Metal added	Metal Temp. °C	Metal Mass, grams	Water Mass, grams	Water Temp. °C	Final Temp. °C	Change in Temp., °C		Heat supplied to water calories
						metal	Water	
iron	100	70	70	20	28	↓72	↑8	560
aluminum	100	70	70	20	35	↓65	↑15	1050
copper	100	70	70	20	26.5	↓73.5	↑6.5	455

↑ = up ↓ = down

14•10 Laboratory notebook page with heat-capacity experiment data. The equilibrium temperature of the metal and water is recorded in the "Final Temp." column. The equilibrium temperature was 60°C when 70 grams of water at 100°C were added to 70 grams of water at 20°C (pages 350–351). The results are different when hot metal is used instead of hot water.

In this case the temperature of the cool water rose 8°C. The temperature of the iron fell 72°C. So the hot iron supplied 560 calories (8 degrees × 70 calories per degree) to raise the temperature of 70 grams of water 8°C. The 70 grams of iron added much less heat than the same mass of water!

The experiment was set up so that the hot metal could supply heat only to the cool water. And there was no other source of heat present. Nothing other than the iron could have supplied the 560 calories that caused the temperature of the water to rise. In addition, there was no other substance to which the iron or cool water could have supplied heat. Therefore the iron must have supplied all of the 560 calories to the water.

The 70 grams of iron gave up 560 calories to raise the temperature of the water 8°C, thereby lowering its own temperature by 72°C. The notebook page in figure 14•10 shows how many calories each of the other 70-gram masses of metal shot supplied to the 20°C water.

When equal masses of hot water and cool water were added, the temperature of the hot water fell the same number of degrees as the temperature of the cool water rose. So the hot water must have supplied 1 calorie to the cool water for every gram that rose 1°C. And each gram of hot water dropped 1°C for each calorie that it supplied.

On the other hand, each gram of the metals dropped more than 1°C for each calorie they supplied to the cool water. To prove this to yourself, study the data in figure 14•10.

This is where another measurement useful in studying the transfer of heat comes in.

The amount of heat that must be supplied to raise the temperature of 1 gram of a substance 1°C is called the *heat capacity* of that substance. Heat capacity is also the amount of heat that a gram of a substance gives up when its temperature drops 1°C.

The heat capacity of water is 1 calorie per gram per degree. That is, *1 calorie* must be supplied to raise the temperature of 1 *gram* of water 1 *degree* Celsius. Or, 1 gram of water must lose 1 calorie of heat for each 1-degree drop in temperature.

You can calculate the heat capacity of iron with the figures from the experiment in figure 14·8 as follows:

The 70-gram mass of iron supplied 560 calories to the cool water. It gave up these 560 calories, or 8 calories for each gram of iron to do so. To find how many calories each gram of iron gave up for each 1-degree drop in temperature, divide the 8 by the number of degrees the temperature of the iron fell. In this case, the drop was 72°C. If you divide 8 by 72, you get 0.11. So the heat capacity of the iron is 0.11 calories per gram per degree.

You will get the same mathematical result if you divide the 560 calories by 70 grams times 72°C. To find the heat capacity of any substance use the following equation:

$$\text{Heat capacity} = \frac{\text{heat given up or gained}}{\text{mass} \times \text{temperature change}}$$

Put the figures from the experiments with the other metals into this equation.

Table 2 gives the accepted figures for the heat capacities of some common materials.

Table 2

Heat Capacity

Substance	calories per gram per 1°C
Aluminum	0.22
Copper	0.09
Ice	0.50
Iron	0.11
Lead	0.03
Mercury	0.03
Silver	0.06
Water	1.00

TEST YOURSELF

1. *How many calories are required to raise the temperature of 12 grams of copper 5°C?*
2. *How much heat must be supplied to raise the temperature of 600 grams of silver from 0°C to 100°C?*
3. *What mass of water at 96°C must be added to raise the temperature of 30 grams of water from 20°C to 36°C?*
4. *What mass of lead at 100°C must be added to raise the temperature of 50 grams of water from 20°C to 25°C?*
5. *What mass of water at 72°C must be added to raise the temperature of 300 grams of silver from 15°C to 45°C?*

ON YOUR OWN

Why use cooking oil?

Gather together a bottle of cooking oil, water at room temperature, a small saucepan, and two small glasses.

Fill the saucepan ¼-full of water and gently heat it for five minutes. While the water is heating, put about 3 cm of cooking oil in one glass. Put exactly the same amount of water in the other glass.

Turn off the heat and put the pan on a hotpad. Place both small glasses in the pan. Count to 10. Then carefully feel the water in the glass with the tip of your finger. Quickly feel the cooking oil with the tip of the same finger. Did both liquids feel the same temperature?

Count to 30 and feel both liquids again. How does the heat capacity of the cooking oil compare to that of the water?

Heat capacity and heat conductivity are important in the design of everyday objects

Pots and Pans and Other Things

As long ago as the Stone Age, people made pots out of ceramics. This material was used almost all over the world. But ceramic cooking pots have two serious problems. They tend to break at high temperatures. And, of course, they break when dropped. So hundreds of years ago many people gave up ceramic cooking pots in favor of metal ones.

Now scientists have developed new heat- and shock-resistant ceramics. Some are so strong they can be used in the nose cones of rockets. With the development of these stronger materials, cooks and designers again became interested in the heat-related, or thermal, properties of ceramics.

Take the frying pan as an example. It must be made of a material that will conduct heat quickly from the outside to the inside. But the material should not give off so much heat that the pan can become hot unevenly. Such a situation produces unevenly cooked food. And the pan shouldn't be so thick that it will buckle from expansion when heated.

Metals meet some of these requirements, but have problems with others. Ceramics enter the scene here. They do not conduct heat as well as metals. So ceramic pans keep a more even temperature than metal pans. Ceramics also do not expand as much as metals. So ceramic pans do not buckle when they are heated.

Though ceramics have made a comeback, metals are still the most popular for pots and pans, for a very good reason. They are the best conductors of heat. A metal pan will get hot much more quickly than a ceramic one of the same size. And though some ceramics are shock-resistant, metal pots and pans are still less likely to break if dropped. But metal pots and pans buckle when they are overheated.

Metals have some good points and some drawbacks for pots and pans. The same is true when metals are used for other things. Window frames are an example.

14·11a Ancient Egyptian ceramic bowl

14·11b Modern ceramic cookware

In terms of thermal properties, wood makes better window frames than do metals. Wood does not conduct heat easily and it expands very little when heated. Plaster, brick, and other common building materials have thermal properties similar to those of wood. So wooden window frames expand and contract with the walls that surround them. But they do have a drawback. Wooden window frames must be painted often to protect the wood from dampness. If they are not cared for, wooden window frames will rot.

To avoid the painting and scraping wood needs, architects began to use metal window frames. But the metal window frames caused a new set of problems. Metal conducts heat so well that the window frames become icy in the winter and hot in the summer. In addition, the metal contracts with cold more than either the wall around it or the window glass. Thus, a metal window frame lets in cold air in the winter. In the summer, the metal expands more than the wall, and the windows become hard to open.

14·12a The wooden window frame is clear in the winter.

14·12b The metal window frame can become iced over.

14·13 Fiberglass insulation being installed in the attic of a house.

Modern metal buildings are affected by the same thermal properties as metal window frames. An architect who designs a metal building must allow for expansion and contraction of the metal. Some aluminum or steel buildings have the same kind of tooth like seams as concrete bridges. On other buildings, the architects ask for special mixtures of metals called alloys. Most alloys have different thermal properties than the original metals. One alloy, invar steel (about 65% iron and 35% nickel), expands only about one fortieth as much as ordinary steel. Other alloys expand even less. But such alloys cost more than ordinary metals.

The problems in a modern glass building differ from those in a metal building. But there are just as many of them. One problem concerns the heat that enters a glass building when the sun shines on it. Another problem involves the heat that leaves the building when the weather is cold. The need for privacy is not the only reason that people living in all-glass buildings have floor-to-ceiling curtains. The curtains help keep the heat from escaping in winter and entering in summer.

Thermal properties of building materials also affect the design of ordinary houses. Solid stone walls will keep a house warm in winter and cool in summer. But they are expensive and must be very thick. So builders have found other materials to do that job. As long as air does not move around, it does not transport heat well. So houses are insulated, or protected from too much heat in summer and too little in winter, with materials that trap air. These materials are lightweight, inexpensive, and effective (figure 14·13).

Industrial designers and manufacturers must be aware of the thermal properties of other kinds of materials also. Automobile engines, furnaces and heating ducts, stoves and refrigerators, roads and bridges—all depend upon the thermal properties of the materials of which they are made.

The history of the machines that convert heat to energy of motion

Heat Engines

Steam

The ancient Greeks knew how to convert heat into the energy of motion. One named Hero made a steam toy called an *aeolipile* (ē′ol ə pīl′). It was a flask with a small opening (figure 14·14). Hero mounted the flask so it could turn. Then he filled it with water and heated it. Steam escaping through the opening made the flask spin.

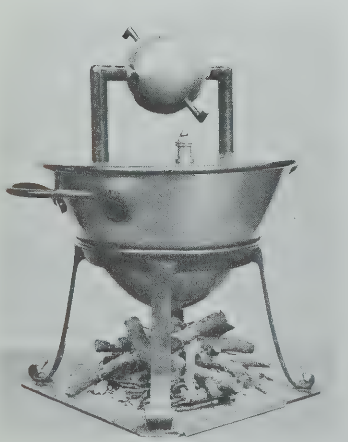
The aeolipile remained a toy because the Greeks did not feel a need for machinery to do work. The rich had horses, oxen, or slaves to do their work. The rest of the people managed without any of these. This was the case throughout the world until the 1600's.

Up to that time people generally did work at home or in small shops. They made cloth and other ordinary things that way. By the 1700's people were beginning to try things that had never been tried before. They started working together in big groups in factories. Windmills or animals supplied power for the machines. But these simple sources could not provide enough power. More complex and more powerful machines were needed.

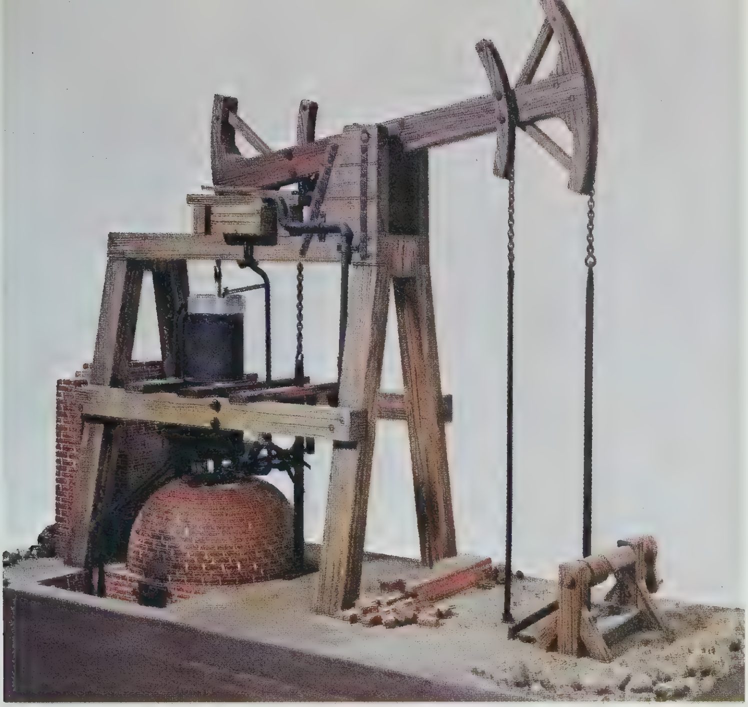
The need for more powerful machines was greatest in the mines. Metals were very important and there were serious problems in mining them. The deeper a mine was, the more water seeped into it. So more water had to be pumped out. At first, windmills and animals supplied power to the pumps that removed the water. But these pumps could not remove enough water fast enough.

The early steam engines were developed to increase the amount of water that could be pumped out of the mines. Thomas Savery, an English military engineer, was the first to make use of the power of steam in a steam engine.

The Savery engine kept the steam in a small container. Because steam has a great tendency to expand, it pushed very hard against the container sides, one of which was movable. The movable side, called a piston, was pushed outward. This motion was transferred to move the pump. However, Savery's engine had a serious problem. The pressure in the container could become too high. It was likely to explode.



14·14 Hero's Aeolipile



14·15 Model of the Newcomen engine. The large wooden beam was balanced in the center. The piston hanging from the lefthand side of the beam fits into the grey cylinder. Steam let into the cylinder forced the piston up. The lefthand side of the beam rose and the righthand side of the beam went down. Cold water was then sprayed into the cylinder to condense the steam. When the steam pressure was gone, the piston dropped. The lefthand side of the beam fell. And the righthand side of the beam rose again. The righthand side was attached to the piston of a pump in a mine.

Another Englishman, Thomas Newcomen, invented a steam engine that could work at a pressure no higher than that exerted on the earth by the atmosphere. Newcomen's engine cost more to run, but it did the job more safely (figure 14·15).

James Watt, who is usually given credit for inventing the steam engine, was really trying to improve on the Newcomen engine. Watt developed an engine which was more efficient and much cheaper to run than Newcomen's engine. Watt's engine, like the earlier ones, was for pumping water. But it was the first commercially successful one. He continued to work on it until, in 1783, he patented a steam engine that could be used for purposes other than pumping water out of mines.

Watt's steam engine was so successful that it led him to work out a way of measuring the rate at which engines do work. Watt needed a basis on which to charge for the use of his engines. He decided to compare the amount of work a steam engine can do with the amount of work a horse can do. So he did research to find out just how much work a horse does.

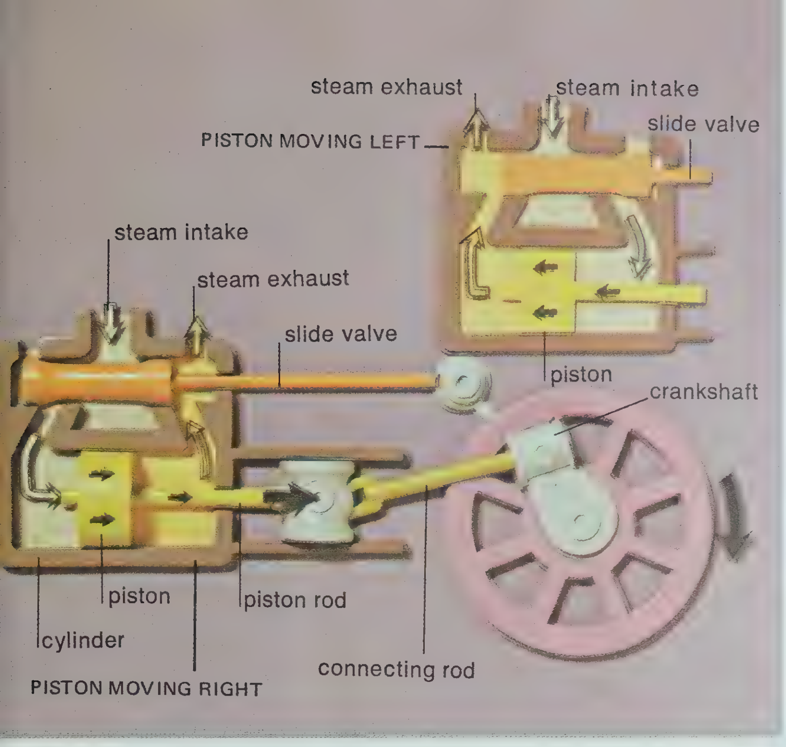
Watt found that a strong horse can raise a weight of 150 pounds about 3 2/3 feet in one second. He called this rate of doing work—550 foot-pounds per second—one horsepower. (Multiply 150 pounds by 3 2/3 feet to get 550 foot-pounds.)

14·16 Model of the Watt engine. In this engine, the condenser and the cylinder were separate. The cylinder did not have to be reheated for each stroke of the piston. Thus the engine needed less fuel and was less expensive to run.

Watt measured the work in foot-pounds because those were the units used in England during the 1700's. The metric system, developed in France in 1791, did not exist when Watt did his research. But we can redefine horsepower in metric units. One horsepower in metric units is equal to 75 kilogram-meters per second or 735.5 watts.

It is impractical to use real horses when you need a lot of horsepower. So more powerful and more efficient machines were invented. Steam engines were developed that could provide power for the machinery in factories. The steam locomotive and the steamship improved transportation and speeded up the shipping of products needed by factories and made by them.

The principle behind the steam engine is simple. When you supply enough heat to water to cause it to boil, it turns into steam. Steam takes up about 1700 times as much space as the water from which it formed. If you boil the water in a closed container, the steam pushes against the sides of the container. So if you make one side of the container movable, the steam will push against it and move it. The movable part of the steam engine is called the *piston* (figure 14·17).

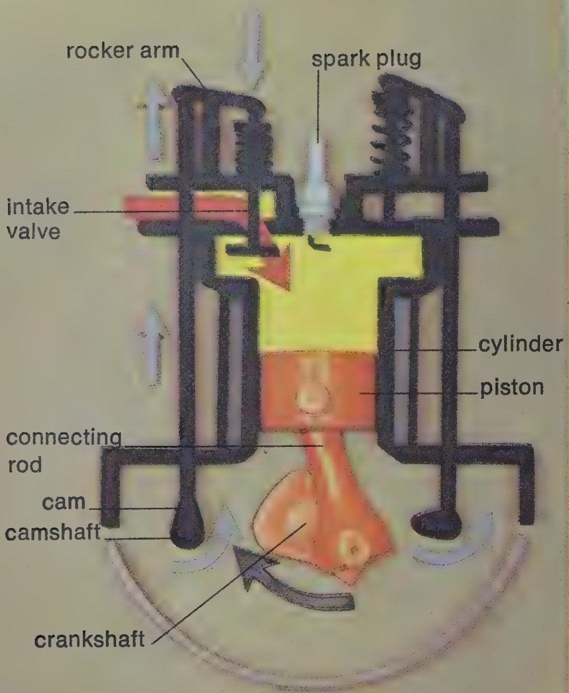


14·17 Modern reciprocating steam engine. The slide valve is open, allowing steam to enter the lefthand side of the cylinder. The steam forces the piston to the right. Used steam is pushed out the righthand vent. The piston rod pushes the connecting rod which moves the crankshaft. The wheel turns to the right. The slide valve is then pulled back, allowing steam to enter the righthand side of the cylinder. The steam pushes the piston to the left. Used steam is pushed out of the lefthand vent. The piston rod pulls the connecting rod which now pulls the crankshaft. The wheel keeps turning toward the right.

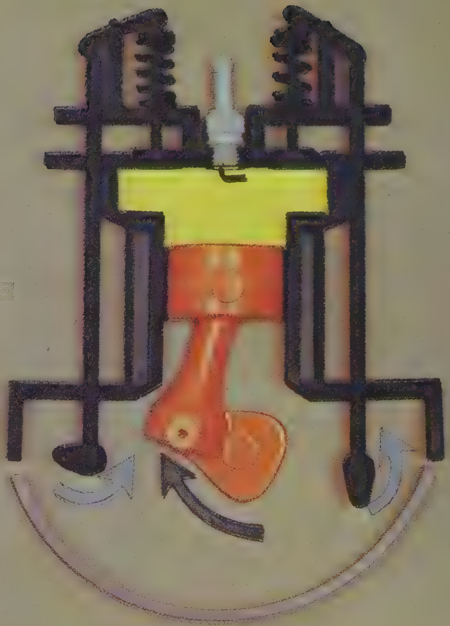
None of the steam engines existing in the late 1700's and early 1800's was very efficient. They were all *reciprocating* engines. That is, their pistons moved back and forth. This piston motion caused much vibration. And the largest of these engines could deliver only 6500 to 7800 horsepower. But the steam turbine, a new heat engine invented in the 1880's, vibrated very little. It took up less space and it could produce up to 60,000 horsepower.

A steam turbine has blades mounted on a metal core that can turn (figure 8·16, page 200). When a jet of steam hits the blades, the pressure of the steam causes the blades and the core to rotate. Thus, no other parts are needed for a steam turbine to provide high-speed rotating motion.

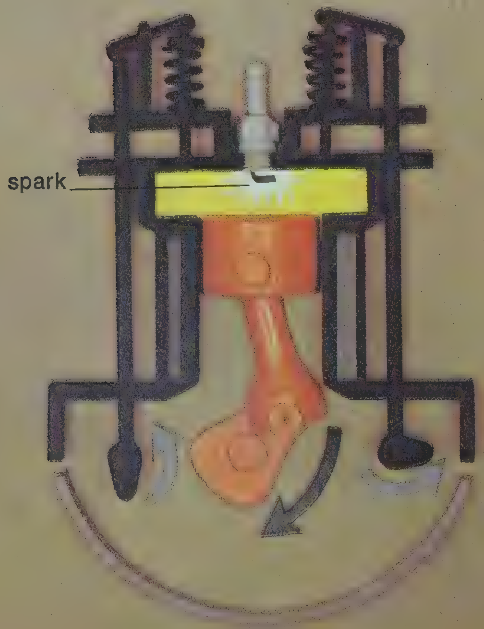
Steam turbines were first used to propel steamships. At present they are most widely used to generate electricity (see page 200). Steam turbines could generate so much electricity that a variety of electric motors were developed to make use of it. Electric motors quickly replaced the small steam engines as power sources for factories. But electricity and the electric motor did not remove the need for steam and other heat engines. A whole series of small heat engines was developed throughout the 1800's. In the new engines, heat was supplied to many substances other than water. But these engines did not become popular until fuels such as natural gas and gasoline became commercially available.



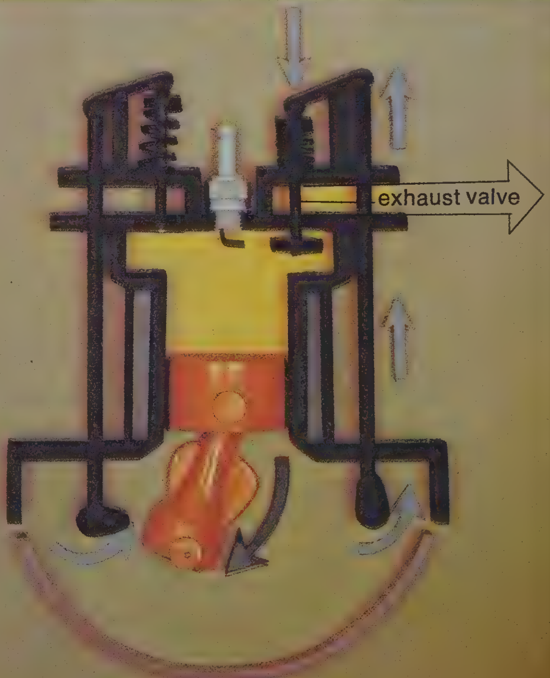
INTAKE STROKE



COMPRESSION STROKE



POWER STROKE



EXHAUST STROKE

Other heat engines

Small heat engines are still very useful in many places. Public buildings such as schools and hospitals often have gas-powered or oil-powered steam engines to generate electricity in emergencies. The automobile or internal-combustion engine, the diesel engine, the gasoline-burning or gas-turbine engine, and the jet airplane engine are all heat engines. Each of them depends on the application of heat.

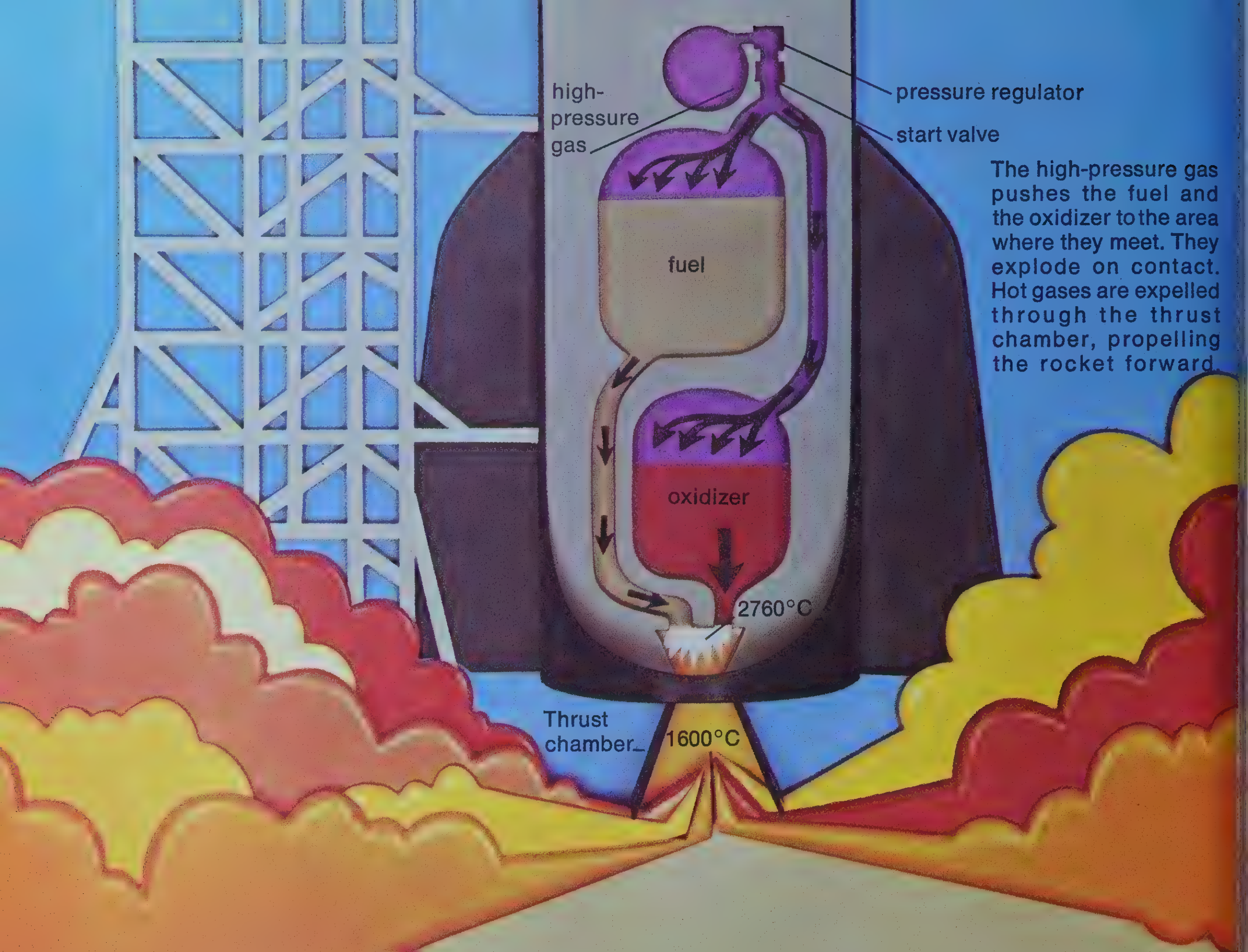
In the internal-combustion engine, fuel is burned in the piston chamber rather than in a separate combustion chamber (figure 14•18). The burning fuel forms hot gases that expand against the piston. As the piston returns to its original position it pushes out the gases. Like the piston steam engine, the internal-combustion engine is limited in size. The need for larger engines, and the success of the steam turbine led to the development of the gas turbine.

The gas-turbine engine can provide power for something as large as an airplane or an ocean-going ship. In the gas turbine, fuel burns in a separate chamber. Then hot gases are expelled so that they push against the blades of the turbine. On some ships, gas turbines have replaced steam turbines. And gas turbines drive the propellers on turbo-prop airplane engines.

The jet airplane engine is also a gas turbine. But it moves the aircraft by jet propulsion. In the jet engine, the stream of rapidly expanding gases is directed out of the engine. As the stream of gases moves out of the rear of the engine, the plane moves forward. The gas turbine engine is very efficient because it has only one main moving part. It wastes very little energy on friction.

14•18 The four cycles of a cylinder in an internal combustion engine. The combination of gasoline and air from the carburetor enters the cylinder (intake stroke). The mixture is compressed (compression stroke). The spark plug ignites the gases and they expand pushing the piston back out (power stroke). The exhaust gases are then pushed out of the cylinder (exhaust stroke).

The engine is built so that the power stroke of each cylinder takes place at a different time. Thus the crankshaft keeps turning, moving the piston up and down through the three non-powered strokes.

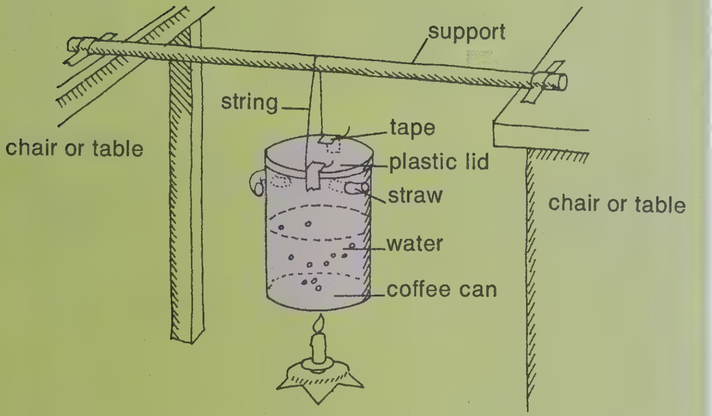


The high-pressure gas pushes the fuel and the oxidizer to the area where they meet. They explode on contact. Hot gases are expelled through the thrust chamber, propelling the rocket forward.

Rocket engines are similar to jet engines. In fact, you could think of them as jet engines that contain all their fuel within the same system. Rockets burn their fuel very rapidly—almost in a controlled explosion. The great amount of power produced by the fuel "explosion" propels the rocket-powered vehicle forward for a great distance.

Our society has become dependent on the machines run by heat engines. More efficient heat engines are being developed every day. And research goes on to make better fuels to run the tools of our age with less pollution.

ON YOUR OWN



The Aeolipile

You can make your own model of Hero's aeolipile with these materials:

1 small coffee can that has a plastic lid
1 nail, 6-mm across
2 bendable drinking straws
1 short candle in a holder
String
Tape

Make sure that the can is clean and the lid fits tightly. Use the nail to pierce a hole in each side of the tin can, about 2 cm from the top. Force the bendable end of a straw about 1 cm into each hole in the can. Bend the straws and cut off the ends as shown.

Remove the cover of the can and pour hot water into it to a depth of 5 cm. Put the cover on tightly. Attach the string to the can with tape so that you can suspend the can by the string.

Suspend the can from a support so that it is free to turn. Use the candle to heat the water in the can. When the water boils, the steam should escape through the straws and the can should turn. Notice the direction in which the can turns.

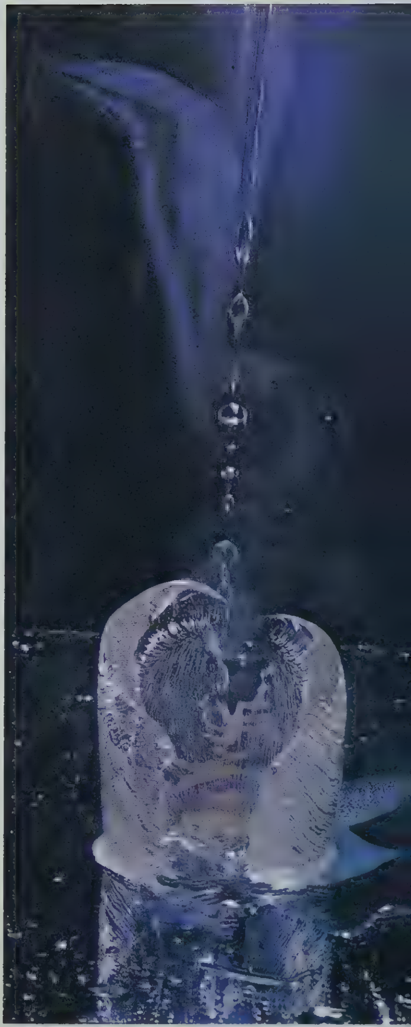
Chapter 15: Boiling Water and Melting Ice

15

The teakettle whistles while you're out of the kitchen. As the water in the kettle boils, it turns to steam. It's escaping steam that makes the kettle whistle.

Ouch! You shouldn't have grabbed the metal handle of the kettle with your bare hand. The handle wasn't in contact with the fire, but it was hot enough to burn you. The metal conducted heat from the bottom of the kettle, which was over the fire, to the handle. An ice cube against the burn will make it feel better. The ice melts when it touches your warm finger.

Ice, water, and steam are the same substance, but ice is a solid, water is a liquid, and steam is a gas. This chapter is about the structure of solids, liquids, and gases.



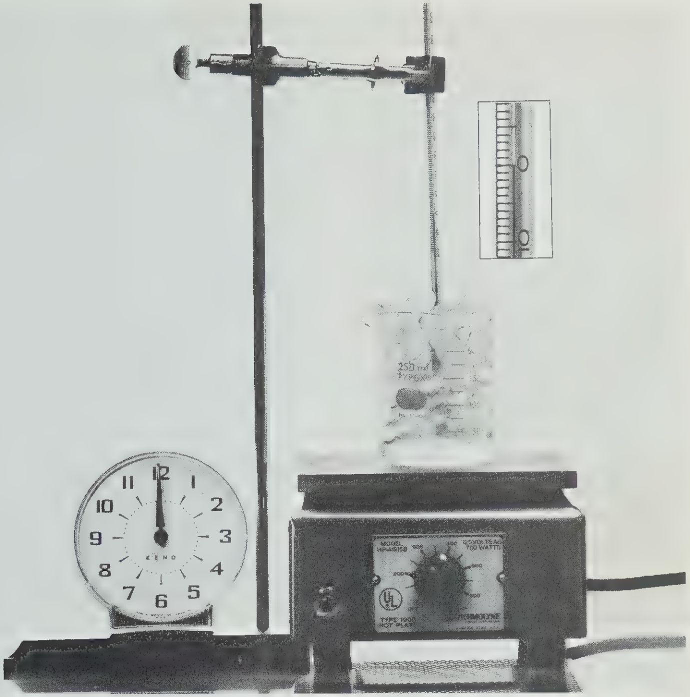
Water is dripping onto the ice cube. Water vapor or steam is rising from the cube.

Melting ice

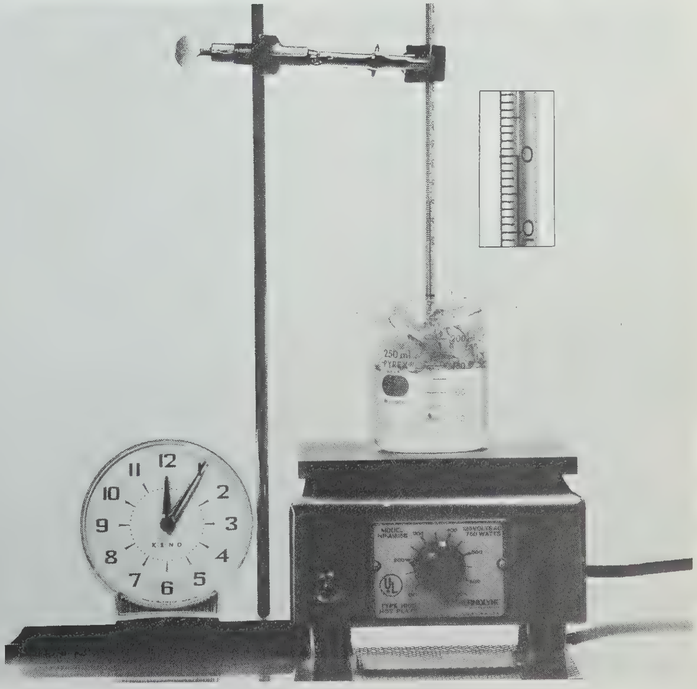
Nothing is quite as refreshing as a cold glass of water on a hot summer day. To be really cold, the water must contain some ice. The water stays cold until all the ice has melted.

The experiment in figure 15·1 shows why melting ice keeps the water cold. Other substances act the same way ice does when they change from their solid to their liquid states. In the experiment, some finely crushed ice with a thermometer stuck into it sits in a beaker. The beaker rests on a hot plate. The hot plate is at a very low setting. A timer stands behind the hot plate. Nothing is added to or removed from the beaker during the experiment. The same mass of water is affected by the same amount of heat in any 5-minute period.

You can see what happens to the temperature of the water—solid and liquid—by referring to figures 15·1a-d. Notice the temperature of the melting ice in the beaker over a 5-minute period. Compare it to the change in temperature of the melted ice (water) over a 5-minute period.



15·1a

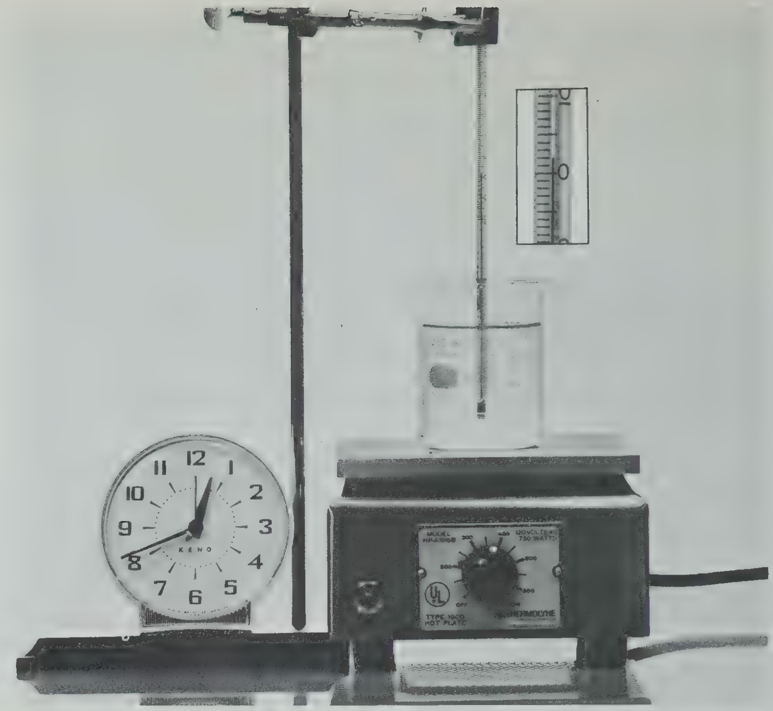


15·1b

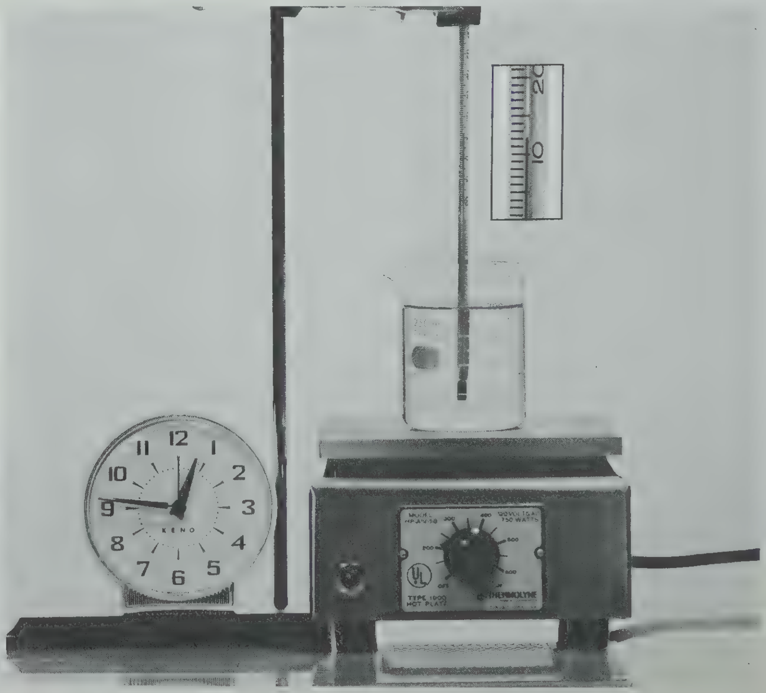
The same amount of heat was supplied to the ice over a 5-minute period as was supplied to the melted ice over the same amount of time. But there is no change in the temperature of the ice. In fact, there is no change in the temperature of the ice until it has almost completely melted.

The temperature of the water containing ice begins to rise slowly when most of the ice has melted. The heat being supplied by the hot plate raises the temperature of the water. The warmed water then supplies heat to melt the remaining ice. By the time all of the ice is melted, the temperature is slightly above 0°C.

In the experiment, the heat supplied with no resulting change in temperature must have been used to melt the ice. As soon as the ice melted, the temperature of all the water in the beaker began to rise (figure 15·1d).



15·1c

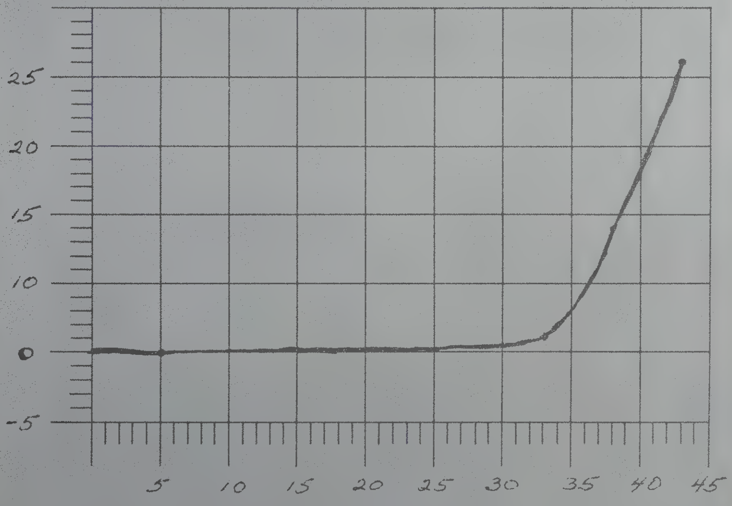


15·1d

MELTING ICE

Time, minutes	Temp °C
0	0
5	0
10	0
15	0
25	0
33	2
38	14
43	26

Plot above data on this graph



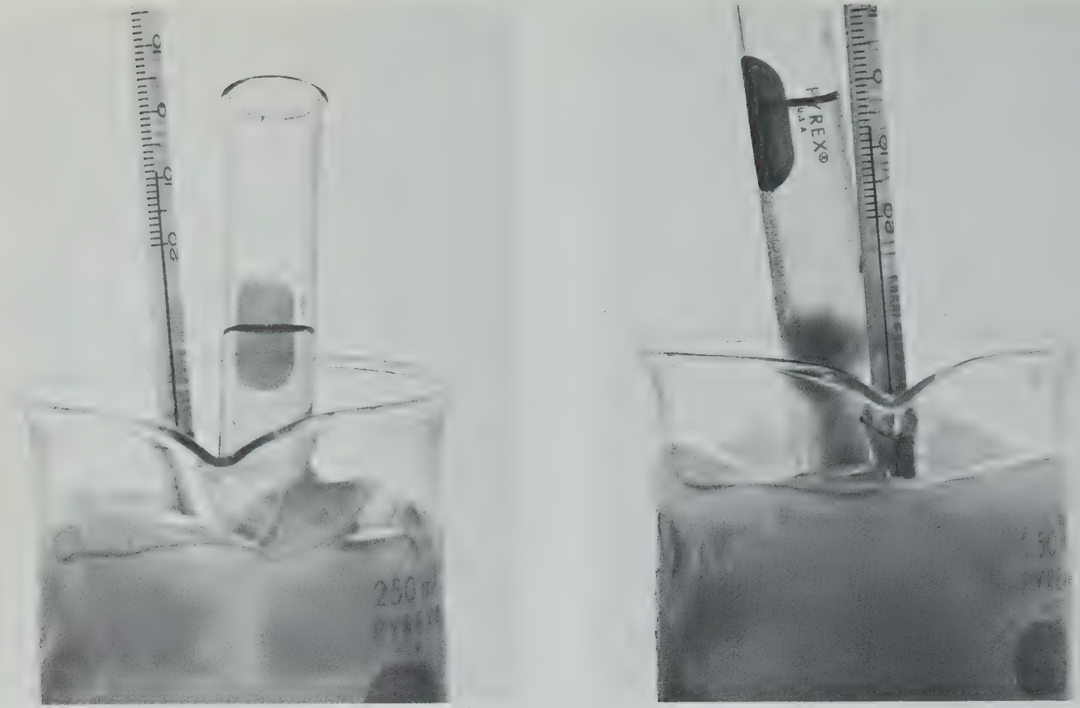
Time, minutes

If it were possible to attain temperatures high enough to melt a piece of aluminum in the classroom, you would find that the same thing happens to aluminum during melting. Its temperature remains constant, at its melting point, until the piece of aluminum is melted.

The heat that must be supplied to a solid at its melting point for it to melt is called the *heat of fusion*. The heat of fusion of any solid, from an ice cube to a load of scrap iron, is the number of calories that must be supplied to change 1 gram of that solid to a liquid.

When heat equal to its heat of fusion is used to change a solid to a liquid, there is no change in temperature of the substance being melted.

15·2 Laboratory notebook page. *Top:* Data from student's ice melting experiment. The temperature of the melting ice and water is recorded at 5-minute intervals until the ice is melted. It is again recorded at 5-minute intervals after the ice is melted. *Bottom:* Graph of time versus temperature during and after melting of ice.



15·3 The temperature of the salt-ice mixture rises as the water inside the test tube freezes.

Substances that melt can also become solid again. The process is reversible. Water is frozen to obtain ice. And molten aluminum hardens into aluminum bars when it is cooled. When a substance freezes, it gives off heat equal to its heat of fusion (figure 15·3).

Scientists have determined how much heat must be supplied to various solid substances for them to melt. You can compare the heat of fusion of a substance with its heat capacity by using Table 2, page 362 and Table 1, here. Does the substance that has the lowest heat of fusion have the lowest heat capacity?

Table 1

Heats of Fusion

Substance	calories per gram
Alcohol	25.0
Aluminum	77.0
Copper	42.0
Ice (water)	80.0
Lead	5.9
Mercury	2.8
Oxygen	3.3
Silver	21.0
Sulfur	13.0
Tin	14.0

ON YOUR OWN

Cooling it

Fill two glasses half full of cold water. Put an ice cube in one glass.

Feel the water in each glass with the tip of your finger. The water in each glass should be about the same temperature when you first touch it. Keep touching the water every few minutes until after the ice has melted. Explain the changes in temperature in terms of the absence or presence of heat of fusion.

Boiling water

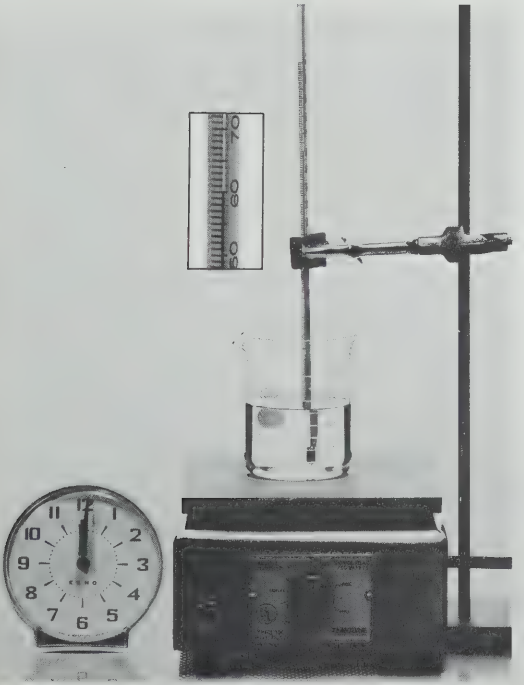
You put a pot of water on the stove to boil so you can make a cup of hot chocolate. Then the telephone rings and you forget all about the boiling water. When you remember and run to the stove, the pot is almost empty. The amount of water left in the pot depends on how much water you put into the pot originally and how long it had boiled.

Of course the boiling water became steam. It changed from a liquid to a gas. But there is more to it than that. Consider the experiment in figure 15·4.

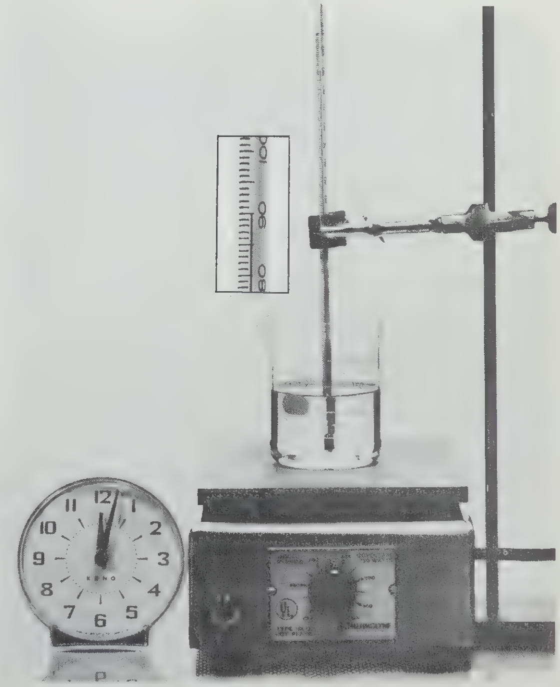
The photographs show a thermometer in a cup of water. The cup sits on a hot plate kept at a medium setting. A timer is behind the hot plate. No water is poured out of the cup during the experiment.

Notice how long it takes the temperature of the water to rise from 60°C to 90°C. When the water reaches 100°C, it stays at that temperature (figures 15·4c and 15·4d).

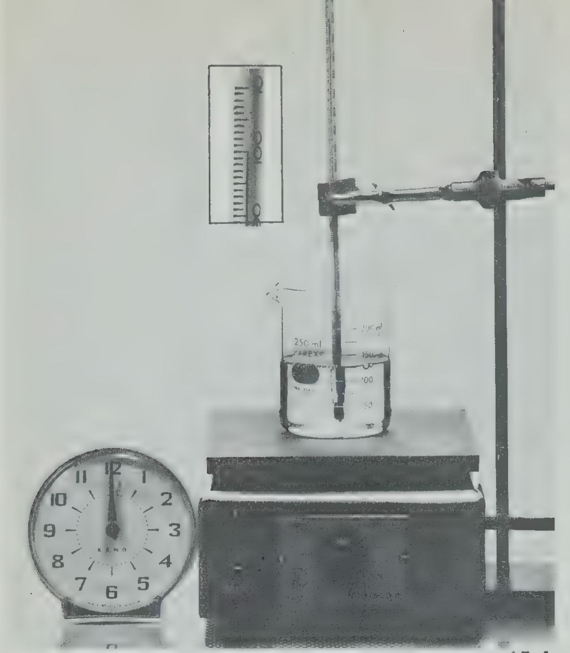
You can use this information and the heat capacity of water, 1 calorie per gram per degree, to estimate how much heat is needed to change 1 gram of water to steam.



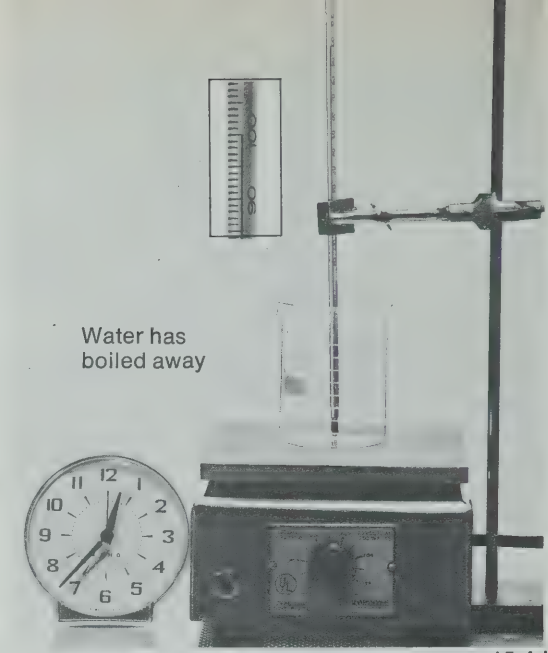
15·4a



15·4b



15·4c



15·4d

Notice that it takes 2 minutes to raise the temperature of the water a total of 30°C (90°C − 60°C = 30°C). Then use the idea that it takes 1 calorie to raise the temperature of each gram of water 1°C. So 30 calories of heat must have been supplied to *each* gram of water during the 2 minutes the temperature was rising.

The water remained at 100°C for 36 minutes while the water was changing to steam. But the temperature of the hot-plate coils did not change. Since 30 calories were supplied to each gram of water during the 2-minute period, you can estimate how many calories were supplied during the 36-minute period. Divide the 36 minutes by 2 minutes, to get 18. Then multiply this number by 30 calories. You get 540 calories, the amount of heat supplied to each gram of water at 100°C during the 36 minutes.

The heat supplied during the 36 minutes without change in temperature is the heat used to change the water to steam. The heat that must be supplied to a liquid to change it to a gas is called the *heat of vaporization*. The heat of vaporization of any liquid is the number of calories that must be supplied to change 1 gram of that liquid to a gas. Use Table 1 (page 378) to compare the heat of vaporization of water, 540 calories per gram, to its heat of fusion.

In more complex experiments, scientists have measured what happens when the process is reversed. They have found that gases give off an amount of heat equal to the heat of vaporization when they are condensed to form a liquid again. For example, if you were to bubble steam through cool water, the temperature of the water would rise as the steam condenses.

There is always a heat balance. The amount of heat supplied to increase the temperature or change the state of a substance is given off when the temperature falls or the substance is returned to its original state.

TEST YOURSELF

1. *How much heat is absorbed by 1 gram of ice when it melts?*
2. *What happens to the heat absorbed by a substance during melting as it becomes solid again?*
3. *Define heat of vaporization.*

Water has some unusual properties

Water—Great Stuff!

It's very convenient to use water as an example to study the solid, liquid, and gaseous states of matter. It's handy just to turn on the faucet. It's inexpensive. You can get a rather large amount of water and a relatively small water bill in comparison. And it's one of the least harmful substances to people. Clean water has no odor and no taste. It can't poison you or seriously damage your clothes. And water does have some other interesting properties.

One of the unique properties of water is that it expands when it freezes. Most substances contract when they change from the liquid to the solid state. But water grows about 10 percent larger. Think about ice cubes in a glass or icebergs in the ocean. Ice floats on water. It has less mass per unit volume than liquid water. Water is densest at 4°C. If you apply heat to water at 0°C, the water will contract until it reaches 4°C. Above 4°C water acts like other substances and expands as it gets warmer. But it never expands enough to be less dense than ice.

This strange behavior of water on freezing makes life on earth possible. If water behaved like other substances, the ice that forms in cold weather would always sink. Rivers, lakes, and even parts of the ocean would be frozen solid in winter. The more northern bodies of water would remain frozen permanently. No plants or animals could live in them.

Another property which makes water unusual is its extremely high heat capacity. It absorbs and releases more heat per gram than most substances. At sea level, water absorbs 1 calorie per gram-degree until it reaches a temperature of 100°C. Because it has such high heat capacity, water makes a good cooling agent for many industrial processes. For example, it absorbs excess heat in steel mills. For the same reason water is also a good heating agent. Many homes and other buildings are heated by radiators filled with circulating hot water.

Water is also an extremely stable substance. It is so difficult to break down water into its component parts that until 1783 scientists thought it was an element. In that year, Henry Cavendish (kav′ ən dish) of England synthesized water from oxygen and hydrogen. In a well-equipped laboratory, it's easy to form water: If heat is applied, hydrogen and oxygen combine explosively to form water. Water also forms when pure hydrogen burns quietly in air. On the other hand, a tremendous amount of energy is needed to break apart water into the original hydrogen and oxygen.

Water comes close to being the "universal solvent." It can dissolve most substances at least a little—even glass is slightly soluble in water. Water dissolves so many substances so well that almost no pure water exists in nature. The water in our lakes, rivers, and oceans consists of a solution of the various substances with which the water has come in contact. But water can be purified. When it changes into a gas it leaves behind the substances that were dissolved in it. So when water evaporates it purifies itself. A supply of pure water is very important. Many living things can exist without oxygen, or without light, but none can exist without water.

ON YOUR OWN

Evaporation

For this activity you will need two thermometers, some water, a small piece of paper toweling, and a rubber band.

Cover the bulb of one thermometer with the paper toweling. Attach the paper to the thermometer with the rubber band. Leave both thermometers near each other on a table for several hours. At that time, both should be at the same temperature.

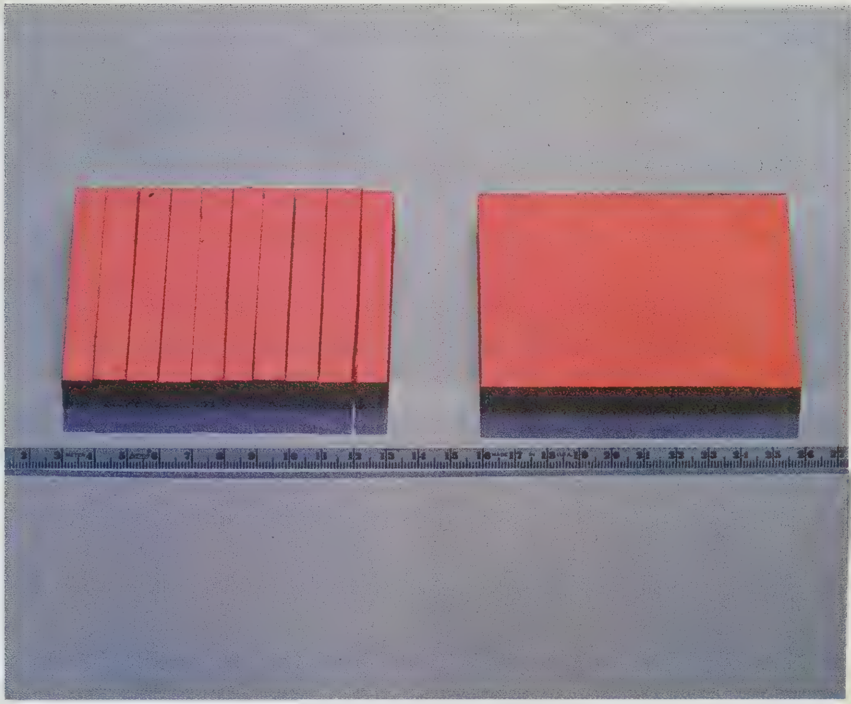
Dip the bulb of the covered thermometer in some water. Put it back on the table. Wait 10 minutes and read both thermometers. What has happened? Why do you think it happened?

Read both thermometers again after 20 minutes. Is there any more difference? Why?

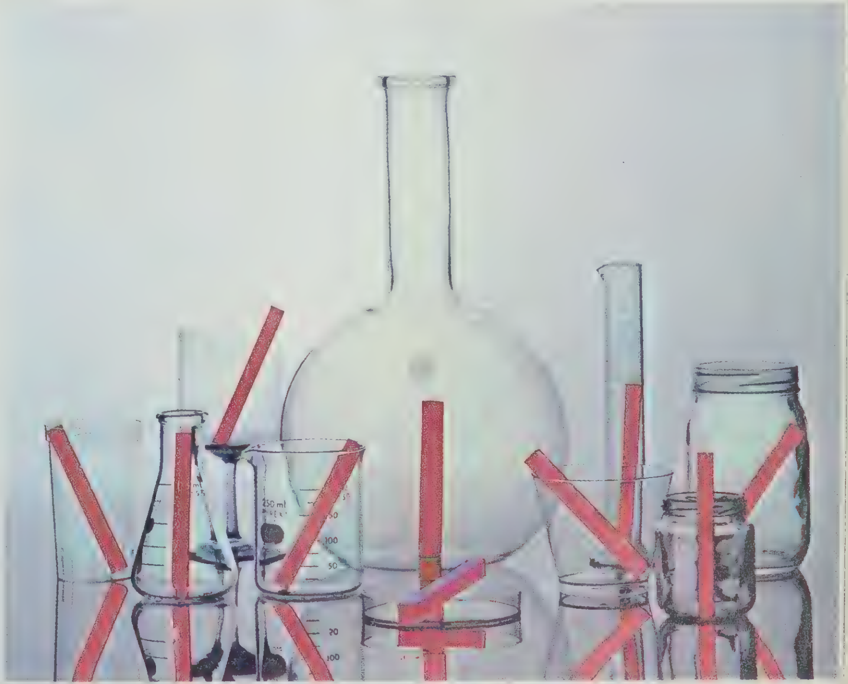
Comparing the states of matter

The previous sections made three points: (1) Heat must be supplied to substances in the solid state in order for them to melt. (2) Heat must be supplied to substances in the liquid state in order for them to vaporize, or become gases. (3) Substances give off heat when they change from gases to liquids and when they change from liquids to solids. All of these are due to the differences among solids, liquids, and gases. Let's consider some of these differences.

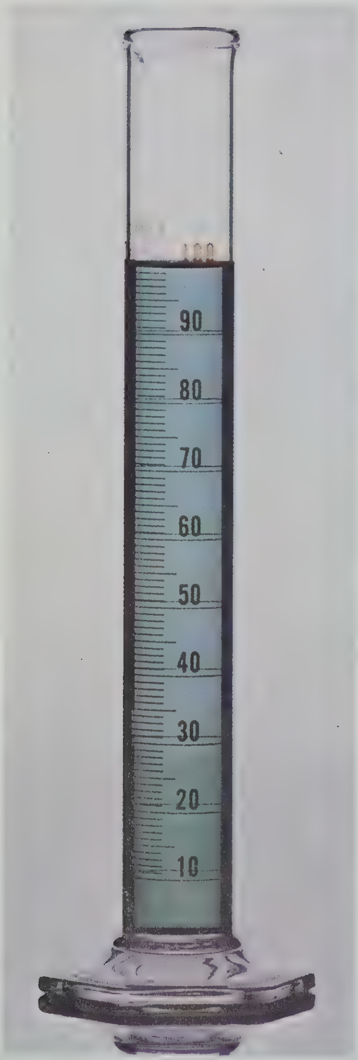
The characteristics of *solids* range from those found in a block of steel to those in a piece of paper or a grain of sugar. But all substances in the solid state have two properties in common. They retain their shape and they retain their volume as long as their temperature stays the same. For example, you can divide a 100-cubic-centimeter block of a solid into 10 equal pieces and place each piece in a cup. Each piece of the solid will keep its own shape and will retain its volume of 10 cubic centimeters.



15·6a



15·6b



15·7a The large graduate cylinder contains 100 milliliters (cubic centimeters) of liquid.

Substances in the *liquid* state range from alcohol to maple syrup to molten metal. But all substances in the liquid state have two properties in common. They assume the shape of the container into which you pour them and they retain their volume, as long as their temperature does not change. When you divide 100 cubic centimeters of liquid into 10 equal parts, each part will assume the shape of the container into which you pour it. But each part will retain its volume of 10 cubic centimeters, just as a solid would.

The characteristics of *gases* vary from those of toxic carbon monoxide to those of the air you breathe or of steam. But all gases have two properties

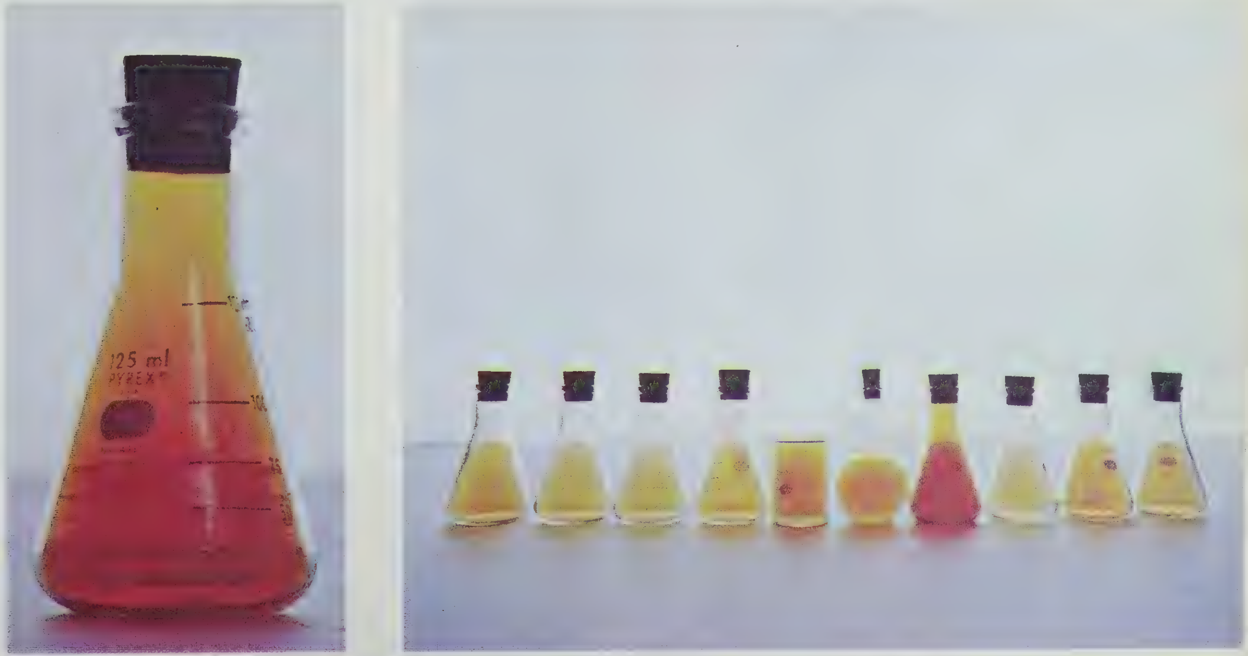
15·7b Each small container holds 10 ml of liquid.

in common. All substances in the gaseous state assume both the shape and the volume of their container. A gas will take up all of the space available to it. You can show that one large flask of a gas with a distinct color will expand to fill 10 large flasks, or that 10 cubic centimeters of a gaseous substance with a distinct odor will expand to fill an entire classroom. Think of how easily you detect even the slightest leak from a gas stove.

A very small amount of a substance can fill a much greater space as a gas than it could as a liquid or solid. And 1 cubic centimeter of that gas will have less mass than it would in either the liquid or solid state.

TEST YOURSELF

1. *In what way are solids and liquids different? liquids and gases?*
2. *In what way are solids and liquids alike? liquids and gases?*



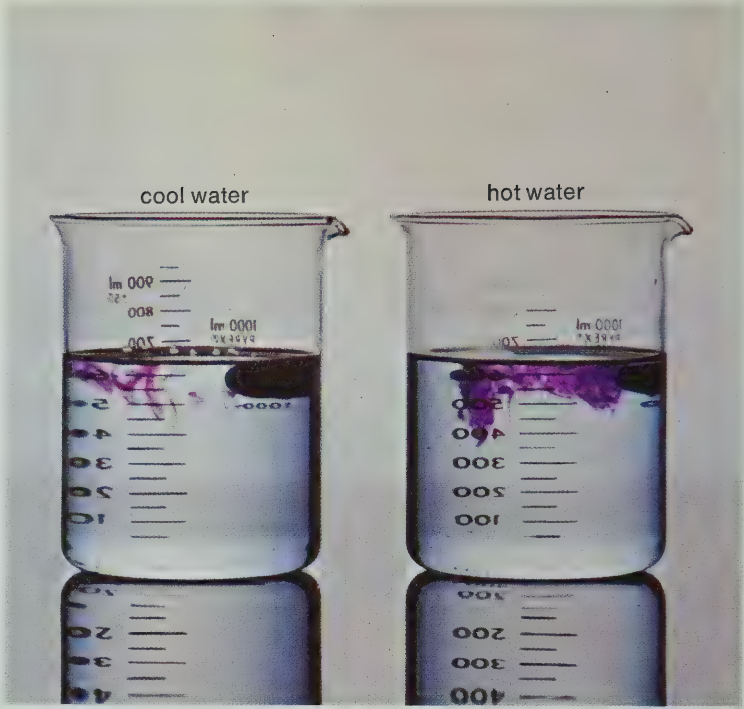
15·8 All of the flasks in both pictures have the same volume. It is easy to find the original flask in the picture on the right. It still contains more gas than any of the flasks it was used to fill.

Supplying heat without change of state

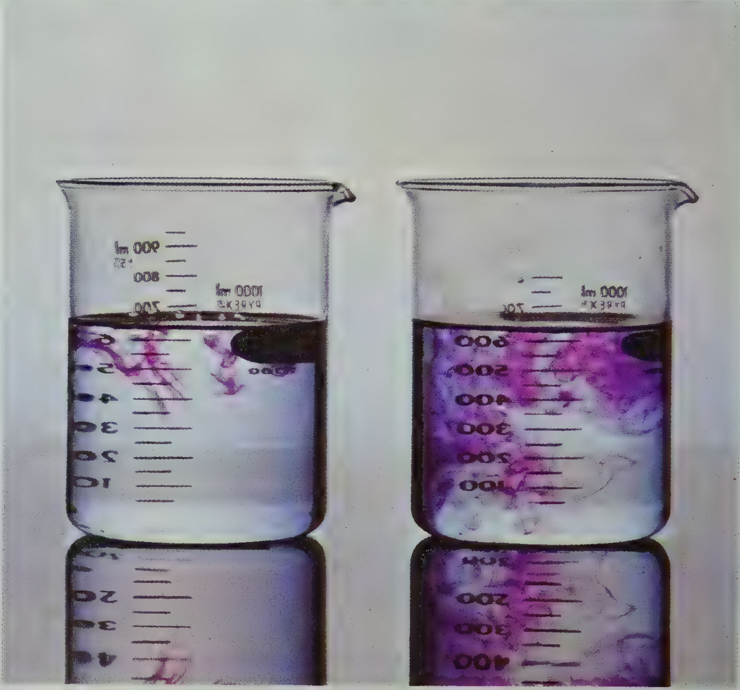
You must supply heat to a solid to bring it to its melting point. And you must supply heat to a liquid to bring it to its boiling point. But supplying heat also causes most solids, liquids, and gases to expand. You used the property of expansion to make a thermometer.

Heat affects still another property of matter. Figure 15·9 shows what happens when you carefully put a drop of ink into a glass of still water. The ink mixes through the still water without any stirring. This mixing is called *diffusion*. The ink diffuses more rapidly with the hot water than with the cool water. And once they have diffused, you have a *solution* of colored water. That is, every part of the water contains the same amount of ink as every other part.

A similar thing happens when you put sugar into a cup of tea. If you do not stir the tea and sugar, the sugar will slowly diffuse into the hot tea surrounding it. First the sugar *dissolves* (forms a solution) in the layer of tea at the bottom of the cup. Then this solution diffuses throughout all the tea in the cup. At that point, a



15·9a



15·9b

15·9c

15·9d

teaspoonful of tea from any part of the cup will taste the same.

If you stir the tea and sugar, or the ink and water, diffusion will take place more rapidly. Stirring brings the ink in contact with more of the water and the sugar in contact with more of the tea. That is, it enlarges the area in which diffusion can take place.

Gases also diffuse more rapidly when stirred or heated. For instance, vapors of cooking food diffuse into the air to carry the odor of a good supper from the kitchen to your nose.

TEST YOURSELF

1. *Describe what happens when a drop of ink diffuses into a glass of water.*
2. *Will a teaspoon of sugar diffuse more rapidly in iced tea or in hot tea?*
3. *Which of the following are solutions?*
   a) oil and water
   b) carbon monoxide and air
   c) salt and soup

The molecular structure of matter

There Is a Model

Examine the variety of solids in figure 15·11. These are all simple solids that undergo change of state when heat is supplied to them. Notice that they all have crystal shapes. (For the time being, let's ignore complex solids like wood or paper that change into different substances when heat is supplied to them.) *Crystals* are regularly shaped pieces of pure substances with angles and flat surfaces.

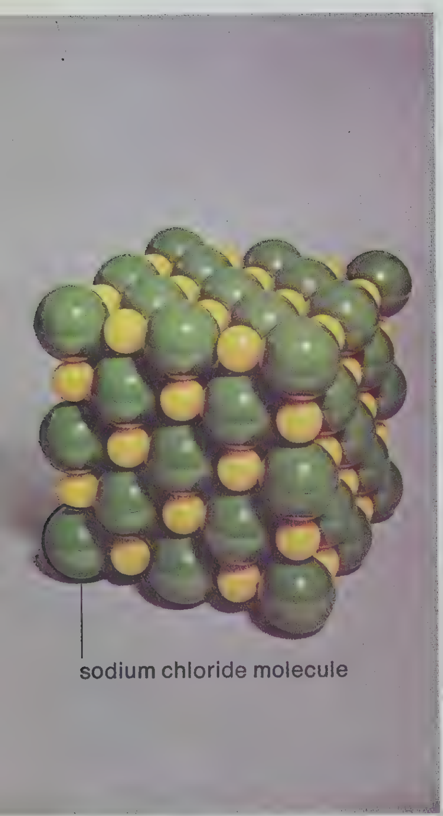
Some crystals are unusually large. These occur only rarely in nature. Very small crystals frequently occur in *minerals* (solid substances in nature that are neither of plant nor animal origin). These can be seen only with a magnifying lens or microscope.

The molecular theory of matter helps explain the structure of crystalline (made of crystals) solids. In this commonly accepted theory, the *molecule* is the smallest particle into which a substance can be divided without changing it into another substance.

According to this same theory, the molecules in crystals occupy fixed positions in regular arrangements (figure 15·10). In the simplest arrangement, the molecules are located at the corners of an imaginary cube. The molecules of sugar, table salt, and many metals are arranged in this way.

The external appearance of a crystal of any of these substances reflects the arrangement of its molecules. Thus crystals of sugar, table salt, and many metals have rectangular or square sides (or *faces*) with right angles between them. Other substances have a more complex arrangement of molecules and more complex crystals.

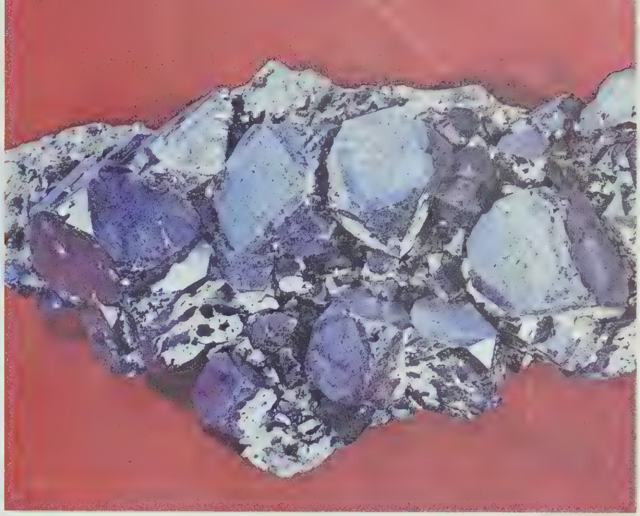
Crystalline solids retain their shape because their molecules are in fixed positions. (Non-crystalline solids, such as wood or paper, also retain their shape because of the positions of their molecules. But this is the subject of the next unit.) Each molecule occupies a given space and therefore the substance is solid.



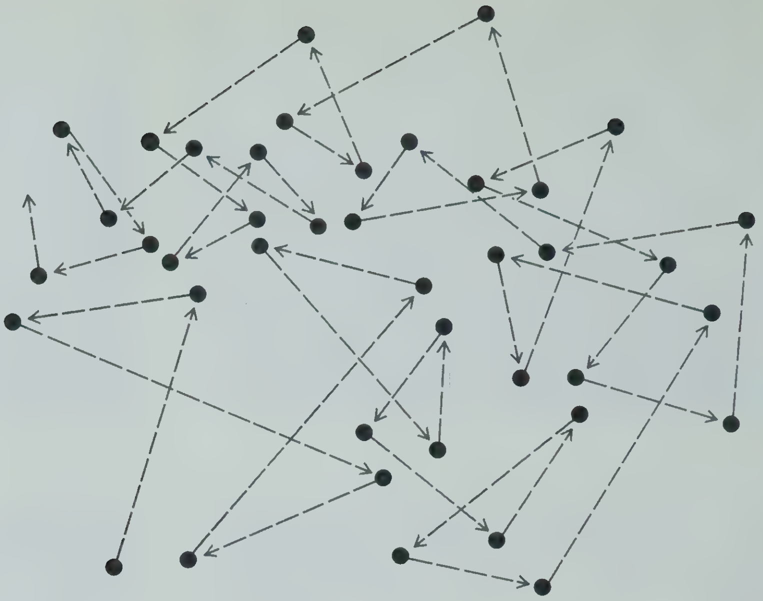
15·10 Structural model of halite (sodium chloride) crystal, showing position of molecules.

15·11 Top left: halite. Top right: galena, an ore of lead. Center left: calcite. Center right: sphalerite. Bottom left: apatite in a different form of calcite. Bottom right: frost on a window.

Crystals of halite, galena, and sphalerite are four sided, or cube shaped. Calcite and apatite are six sided, or hexagonal. Frost crystals are also six sided. But in this photo they are not magnified enough for the shape of the crystals to be seen.



15·12 Zig-zag pattern of a pollen grain during Brownian motion.



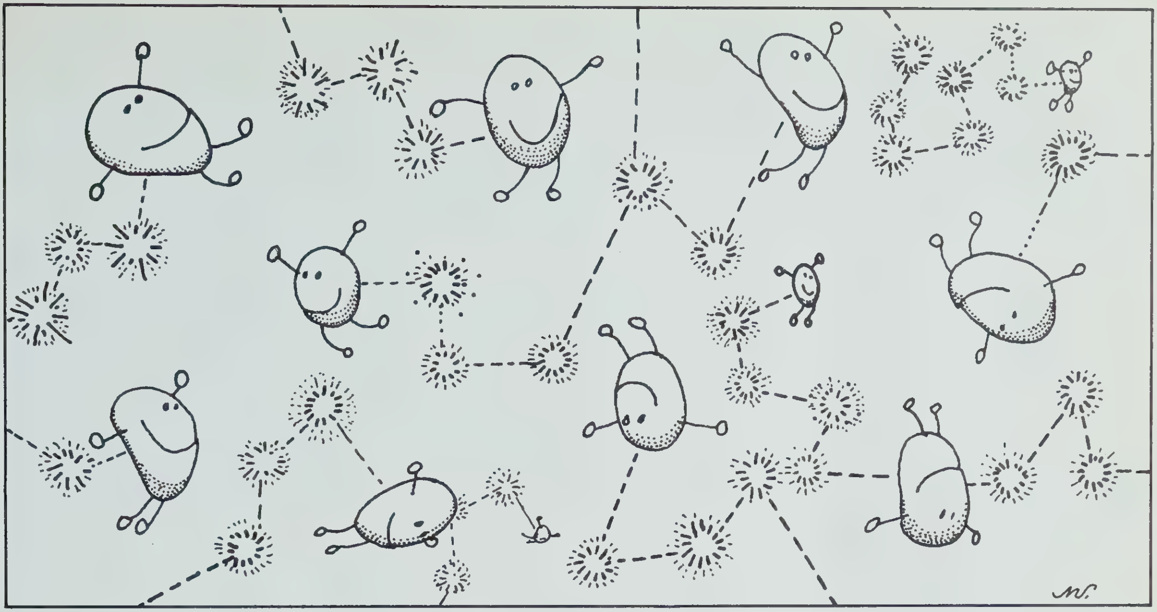
Why don't liquids and gases have shapes?

The molecules of liquids and gases are not bound into the same sort of structure as the molecules of solids. Their readiness to flow and their lack of shape indicate their freedom of motion.

Robert Brown discovered evidence for molecular motion in fluids as early as 1828. Brown, a botanist, was studying pollen grains. He suspended some microscopic pollen grains in water and observed them through a magnifying lens. The pollen grains did not stay still (figure 15·12). They jumped around in random zigzag patterns as if they were constantly being pushed. The activity of the pollen grains is called Brownian motion. Other microscopic particles also show Brownian motion.

Scientists have studied Brownian motion in a variety of substances. They are sure that the motion is not caused by anything within the particles that are jumping around. Instead they think the molecules moving in the liquid push the suspended pollen grains or other particles around. Scientists accept Brownian motion as a form of evidence that much and rapid molecular motion takes place in liquids.

The scientists also found that Brownian motion occurs in gases. You can see Brownian motion when you look through a magnifying lens at dust particles suspended in still air and reflected in a ray of sunlight. The random zigzag movements of the dust particles are Brownian motion. The gas molecules constantly moving in air are bumping the dust particles and making them move around.



15·13 Cartoonist's impression of Brownian motion. Pollen grains are being bounced around by moving molecules of a liquid or gas.

There is other evidence for rapid molecular motion within liquids and gases. Remember how rapidly the drop of ink diffused into the still water or how rapidly cooking odors diffuse through the air. Since the ink was not stirred into the water, the motion of the water molecules must have helped it diffuse. And cooking odors diffuse through still air much more rapidly than ink diffuses through still water. So gas molecules must move even more rapidly than liquid molecules.

Gas molecules are freer or farther apart than liquid molecules. For this reason, a substance has far less mass per unit volume in the gaseous state than it would have as a liquid. The molecules of a gas can spread out enough to enable the gas to fill its container, even if that container is an entire school building.

What are heat of fusion and heat of vaporization?

The molecular theory helps explain what happens when you supply heat to a solid at its melting point. When a crystalline solid melts, the regular arrangement of its molecules disappears. The heat supplied during melting supplies the energy to overcome the force holding the solid molecules in a regular crystalline pattern. The heat energy changes the pattern of the molecules from the regular arrangement of a solid to the freely moving pattern of a liquid. Thus, the heat of fusion of a solid is the amount of heat energy which breaks down the molecular pattern of one gram of that solid.

The same sort of thing happens when you apply heat to a liquid. The heat applied to the liquid overcomes the force that holds the liquid molecules together. The heat of vaporization per gram of liquid is greater than the heat of fusion per gram of solid for a given substance. Therefore, the force between liquid molecules is greater than the force holding the molecules in the crystalline pattern of a solid. The heat supplies the energy to break the liquid molecules apart so that they can move independently through space and fill any container as a gas. Thus, the heat of vaporization of a liquid is the amount of heat energy needed to free the molecules of one gram of that liquid.

Heat without change of state

What happens when you supply heat to a substance and it does not undergo a change of state? The substance becomes hotter, of course. Its temperature rises. And the substance expands as it gets hotter. Its molecules move farther apart. Diffusion occurs more rapidly at higher temperatures. Brownian motion also becomes more rapid as you apply heat. You can watch the pollen grains suspended in water begin to move more quickly as the light under the microscope heats the water. Why?

As you heat a substance, its molecules move more rapidly. This movement takes place in solids as well as in liquids and in gases. The molecules of solids occupy certain positions but they are not motionless. If the molecules of a solid did not move, the solid could not conduct heat or electricity. Each molecule moves constantly or vibrates within its fixed position. The energy of motion of the molecules in a substance increases as the substance gets hotter. Therefore, the amount of heat supplied to a substance affects the total energy of motion of the molecules in that substance.

Heat and equilibrium temperatures

What happens when two substances, each at a different temperature, reach an equilibrium temperature? The energy of motion of the molecules of the hotter substance is greater than that of the molecules of the cooler substance. But scientists have found that

ON YOUR OWN

Diffusion

You can demonstrate the effect of temperature on the rate of diffusion with the following materials:

- 3 water glasses (made of clear glass)
- 1 eyedropper
- Water
- Ink

Fill one of the glasses with ice-cold water that does not contain any pieces of ice. Fill the second glass with room-temperature water. And fill the third glass with the hottest water you can get from the faucet.

With the eyedropper, place two drops of ink in each glass. Try to do this so quickly that it seems as though you put the ink into all of the glasses at exactly the same time. Notice any differences in the speed at which the ink diffuses into the water.

ON YOUR OWN

Crystals

You can grow crystals with many different shapes using materials which can be obtained from a grocery store and a pharmacy:

- 8 water glasses
- 1 hand lens
- 8 25-cm (10-in) lengths of string
- 8 weights
- Boiling water
- Food coloring
- Kosher salt
- Sugar
- Alum
- Borax
- Epsom salts
- Copper sulfate

Procedure: Fill a glass half full of boiling water. Add kosher salt to the boiling water and stir until no more salt will dissolve in the water. Now pour the salt water into a warm glass. Tie a weight to the end of a piece of string and put it in the glass of salt water so that the other end of the string hangs over the edge of the glass. Let the salt water cool slowly. Note the shape of the crystals that form on the string as the salt water cools.

Repeat this procedure for each of the substances listed above that you were able to get. You can see the salt and sugar crystals more clearly if you add 3 or 4 drops of food coloring to the water in which you grow them.

Examine all the crystals you have grown under a hand lens. Notice how they differ.

when a hot substance comes in contact with a cool substance, the molecules of the hot substance begin to move more slowly. That is, the energy of motion of its molecules decreases.

Energy cannot disappear. The energy of motion lost by the molecules of the hot substance must be accounted for. This energy is transferred to the cool substance as heat. There it increases the energy of motion of the molecules of the cool substance. The molecules of the cool substance begin to move more rapidly.

This transfer of energy continues until the molecules of both substances have the same energy of motion. There will be no further transfer of energy between them. They can be said to have reached a state of equilibrium. The energy in transfer between the two objects at different temperatures is *heat*.

Temperature

When a substance is cool, its molecules have little energy of motion, and its temperature is low. When heat is supplied to the substance, the energy of motion of its molecules increases. Its temperature rises. Thus *temperature* may be understood as a measurement of the change in the energy of motion of a substance's molecules.

A thought and discussion question

WATER . . . Water . . . water . . .

"Water, water everywhere; nor any drop to drink," said the famous poet, Samuel Coleridge, who wrote "The Rime of the Ancient Mariner." Millions of persons throughout the world share this problem. They may live on islands in the middle of great seas or on land bordering those seas. But, they cannot drink sea water.

Piping enough fresh water into southern California was easy when Los Angeles and San Diego were small towns. But now they are part of a large, heavily populated metropolitan area. Their water supply has not increased. And the amount of fresh water in the mountain areas nearby is limited.

Other places have similar problems. Northern Mexico has a serious water shortage. A large part of the Middle East is a desert. And the many people who have moved to islands in the Caribbean and Mediterranean seas need sources of fresh water.

The most obvious place to look for fresh water is the sea. Sea water is not drinkable, but it is water. And the salts that make sea water unfit to drink can be removed.

Many of the methods we use to separate sea water from the salts depend on change of state. When water boils and becomes water vapor, it leaves behind the salts dissolved in it. The same thing happens when water freezes and becomes ice. Steam and ice are fresh water and both can return to the liquid state.

The sun provides energy for the oldest method of desalting sea water. In solar distillation, water is evaporated and then condensed. This method requires nothing more than a large area to hold the water and lots of sunshine to heat the water. But it yields only 4 kilograms of fresh water from each square meter of basin area per day. And, it only works when the sun shines. So more efficient methods of desalting sea water have been developed using sources of power other than the sun.

In some of the newer methods, the sea water is also heated to form water vapor and then condensed to produce fresh water. Many of the plants using these processes produce over 1 million gallons of fresh water per day. But they have serious problems that the solar distillation process does not have. Processes that depend on evaporation of sea water need a great deal of energy to heat the water. They also require energy to send the heated sea water through the plant and to remove the fresh water.

The salts in the sea water deposit a hard coating or scale that stops up the water pipes and reduces the capacity of the evaporators. And the hot sea water corrodes (chemically wears away) the metals in the pipes and evaporators. So the evaporators and pipes must be made of special corrosion-resistant metals. And chemicals must be added to the sea water to slow down scale formation. The cost of desalting sea water by these processes is high.

Another process works by freezing sea water to get fresh water. It requires less energy than any of the evaporation processes except for solar distillation. And at lower temperatures less corrosion and less scale formation take place. But the process also produces less fresh water. It can be considered more costly because it requires more or bigger facilities.

The cost of desalting sea water depends on the volume of water desalted by a plant. At present, it costs about one dollar per thousand gallons of fresh water distilled from sea water compared to thirty cents per thousand gallons for water from fresh-water sources. But as larger desalting plants are built, the price will fall. And new dual-purpose plants will reduce the cost even further. Dual-purpose plants are desalination plants that operate with nuclear or coal power plants. Water becomes hot as it cools the power plant. This hot water then heats the sea water for the desalting process. This procedure may reduce the cost of desalting sea water to between thirty-five and fifty cents per thousand gallons. But none of these cost figures include the cost of moving the fresh water to the place where it will be used. The user will have to pay much more for this water than the cost of producing it.

The cost of desalting sea water is high. But we must have fresh water. Is desalination a financially sensible way to provide water for a growing world population? Can we desalt enough sea water to make the desert into farmland and increase world food production? Will we be able to afford the price of food grown on land irrigated with desalted sea water? Could desalination methods purify polluted fresh water? Or must we find a much less expensive way? Think about it.

If you would like to read more about this subject, look up the following topics in *The Readers' Guide to Periodical Literature*, in your library card catalog, or in an encyclopedia:

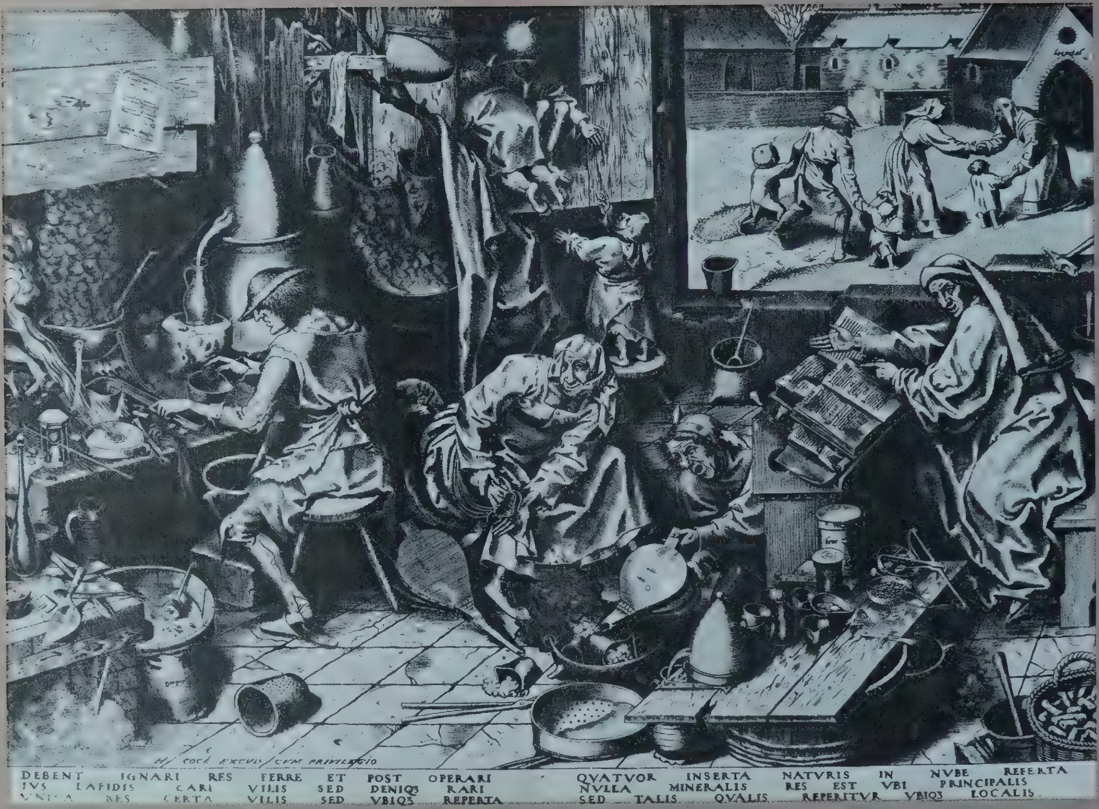
Brackish water
Desalination
Desalting water
Fresh water, production of
Saline water conversion
Water, purification of
Water, quality of

Unit 5: Chemistry

Newspaper headlines read, "Great Lakes Fish Not Edible Because of Mercury," "Automobiles Banned from Downtown Tokyo," "Nitrogen Oxides Drop 80 Percent," "Electric Company Agrees to Use Low-Sulfur Fuels." Stories that describe the fight against pollution mention phosphates killing lakes, pesticides killing birds, phenol making water unsafe, and lead fuels poisoning the air.

What are these things that seem to cause so much damage? You have seen mercury inside a thermometer. It looks the same color as silver. And it is a liquid as is water. Did you know that mercury is extremely poisonous when left in the air? What do you know about nitrogen oxide, sulfur, phosphates, phenol, and lead fuels? Would you say they are alike, almost alike, or completely different?

There are many different things besides these on earth. Some are simple materials and others are very complex. In this unit you will take a closer look at ways in which some of these interact.


H. COCK EXCVD. CVM PRIVILEGIO
DEBENT IGNARI RES FERRE ET POST OPERARI
IVS LAPIDIS CARI VILIS SED DENIQ3 RARI
VNICA RES CERTA VILIS SED VBIQ3 REPERTA
QVATVOR INSERTA NATVRIS IN NVBE REFERTA
NVLLA MINERALIS RES EST VBI PRINCIPALIS
SED TALIS QVALIS REPERITVR VBIQ3 LOCALIS.

This 1558 engraving by Pieter Breughel shows an amateur alchemist at work. He is seeding a mixture with his last gold coin in hopes that the mixture will turn to gold. If he fails, there's always the poorhouse that can be seen through the open window.

Water is being tested for industrial pollutants in this chemistry laboratory. Chemical tests are also done in laboratories equipped with complex devices that look very much like computers.

Chapter 16: Variety Is the Spice of Life

16

The world is like a huge variety store. It is stocked with what seems like an endless supply of different things. When you are out-of-doors, look around you.

The clouds aren't made of the same substances as the grass, or the sidewalk, or the street. The houses are all different, too. Some are made of wood. Others that look like wood may be covered with aluminum siding. Still others may be brick, or adobe, or concrete, or steel and glass.

All these things are made up of various substances. A *substance* is a pure material. Each molecule of a substance has the same definite composition.

Different substances have different properties. One substance melts and boils at temperatures different from other substances. It conducts electricity differently. And it doesn't have the same mass for a given volume as other substances.

There are also other ways by which you can tell one substance from another. Knowing about such things comes in handy in activities as different as cooking, taking care of a car, distilling petroleum, and making chewing gum.

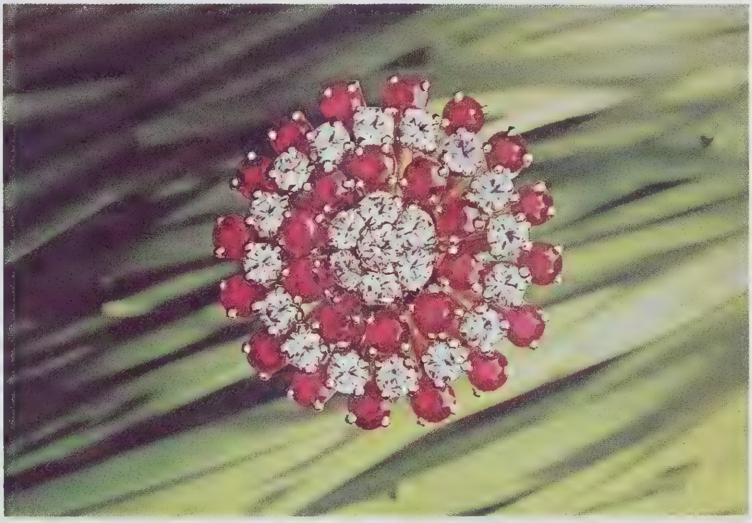
A set of properties

You usually decide whether substances are alike or different by the way they look. A red stone looks different from a clear one. A milky one looks different from both. But are all the clear stones in the pictures made of the same substance? What about all the red stones? Color, transparency, and texture may help you decide whether things are *different*. But you cannot always use appearance to tell whether things are made of the *same* substance.

There is a special test that can be used to tell whether all the clear stones or all the red stones are alike. This test involves the use of precision tools to measure the way each stone bends light.

If each clear stone with the same shape bends light differently, it can be assumed to be made of a different substance. However, two stones that bend light the same may not be made of the same substance. So this property and appearance are not enough information to tell whether two things are made of the same substance.

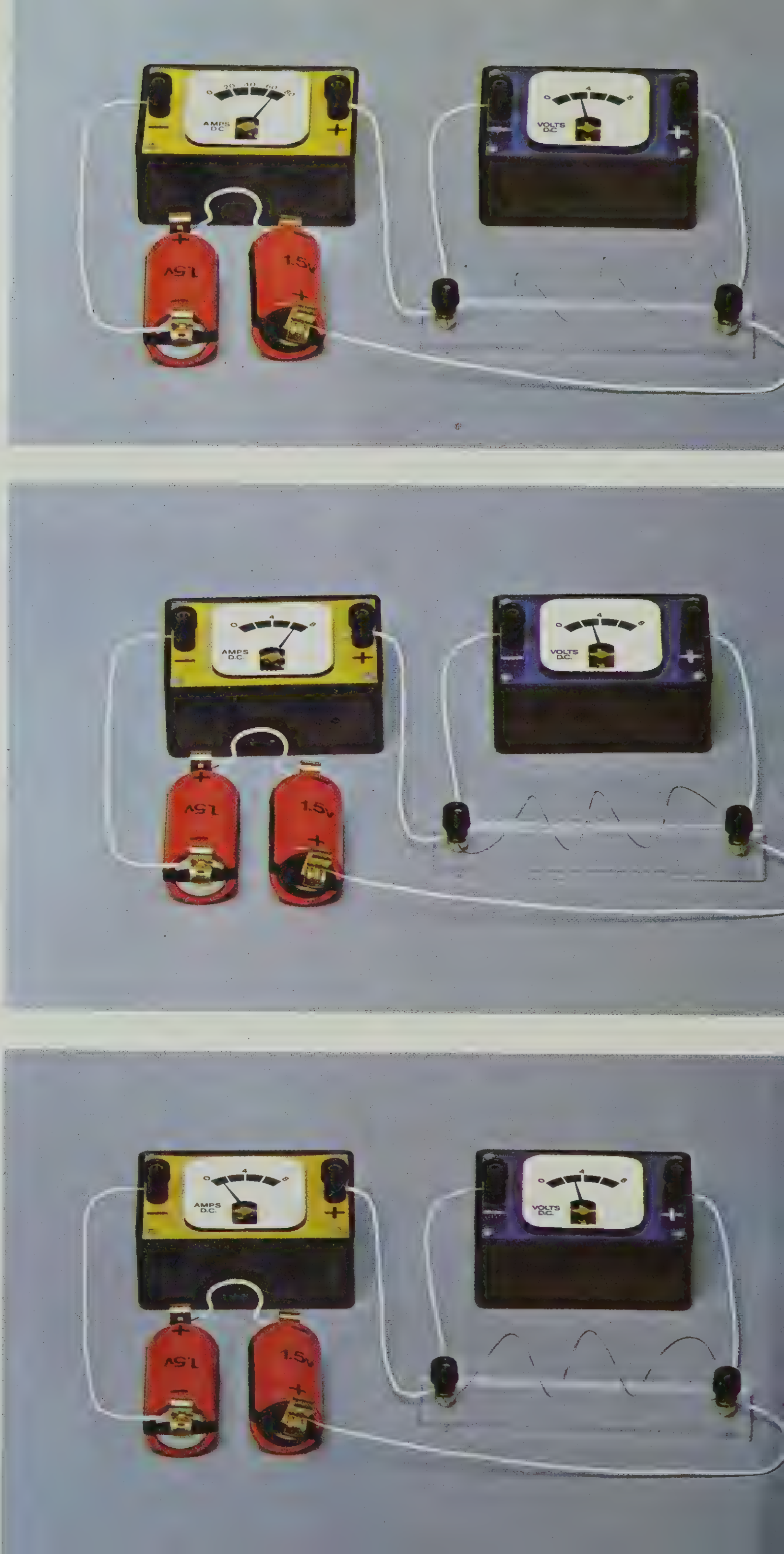
16·1



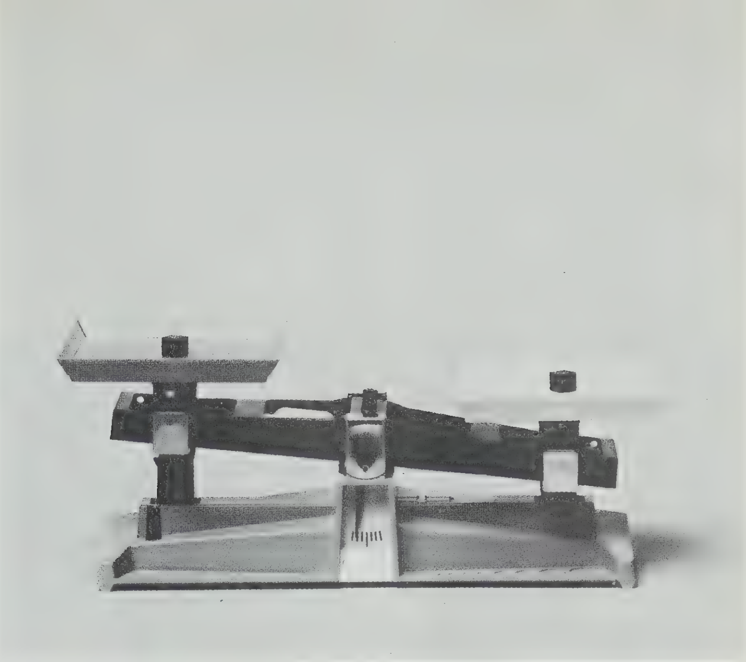
You could test to see how well they conduct electricity. Some substances are better conductors of electricity than others. And still other substances conduct so little electricity that they are called nonconductors.

If the electrical resistance of a substance is low, it conducts well. Gold is a very good conductor of electricity. So are silver and copper. Iron is a good conductor, but it has a higher resistance than gold, silver, and copper. Lead is also a conductor, but it has an even higher resistance than iron.

You might be able to tell these substances apart by placing them in a series circuit with a light bulb and two flashlight batteries. (This setup is a simple conductivity tester.) But in figure 16·2 a voltmeter and an ammeter are



16·2 Electrical resistance is measured in units called ohms. To get the resistance in ohms for each of these wires, divide the voltmeter reading by the ammeter reading. All the wires look the same, but do they all have the same electrical resistance?



16·3

in a circuit with each of three pieces of wire. Now can you tell whether the pieces of wire are made of the same substance?

Another way to tell whether substances are alike or different involves their masses. Comparing the masses of two objects can be rather tricky. For example, a large helium-filled weather balloon could have much less mass than a rock half its size. The weather balloon could also have less mass than a small toy balloon, if the toy were filled with water instead of helium. Unless two substances are exactly the same size, you cannot use their masses to tell the difference between them.

Table 1. Density of Some Common Materials

Solids	Grams per cc	Liquids	Grams per cc
Aluminum	2.7	Alcohol	0.8
Copper	8.9	Gasoline	0.7
Gold	19.3	Kerosene	0.8
Ice	0.9		
Iodine	4.9	Mercury	13.5
Iron	7.9	Olive oil	0.9
Lead	11.3	Water	1.0
Magnesium	1.7		
Nickel	8.9		
Platinum	21.4		
Silver	10.5		
Sugar	1.6		
Wood, balsa	0.1		
birch	0.5 to 0.8		
ebony	1.1 to 1.3		
maple	0.5 to 0.8		
oak	0.6 to 0.9		
walnut	0.6 to 0.7		

Both blocks in figure 16·3 are the same size. Each of the blocks is 1 centimeter long in each direction. So each block has a volume of 1 cubic centimeter (*cc*). And you are comparing the mass per unit volume, or *density*, of the blocks.

The density of solids and liquids is usually measured in grams per cc. A 1-cc block of gold has a mass of 19.3 grams and a density of 19.3 grams per cc. A 2-cc block of silver has a mass of 21 grams and a density of 10.5 grams per cc.

Table 1 lists the accepted values for the densities of some common materials. You can tell whether two substances may or may not be the same by determining the density of each.

There are many more properties that you can use to tell the difference between substances. Each substance always has its own characteristic melting point and boiling point. Different substances do not have the same heat of fusion, heat of vaporization, or specific heat. And the quantity of a substance that will *dissolve* in, or form a solution with, water is also a property of that particular substance.

All of the properties discussed in this section are called *physical properties*. A pure substance always has the same physical properties, no matter where you find it. For instance, pure aluminum is a silver white, shiny, opaque, electrically conducting solid. It always melts at 659.7°C with a heat of fusion of 76.8 calories per gram. Aluminum always has a specific heat of 0.22 calorie per gram, a density of 2.7 grams per cc, and will not dissolve in water.

ON YOUR OWN

Is silverware made of silver?

You can find out using these materials:

1 100-cc (ml) graduated cylinder
1 teaspoon
1 balance or scale
Water

You can measure the volume of any insoluble solid by dropping it into a known volume of water. The solid will displace its own volume of water.

The level of the water in the cylinder will rise, indicating an increase in total volume (water plus solid). The increase in total volume will be equal to the volume of the solid.

Put 60 cc of water into the graduated cylinder. Then drop the teaspoon into the water. It should be completely under water. Note the volume of the water and the teaspoon. The difference in volume is the volume of the teaspoon.

Use the balance or scale to find the mass of the teaspoon. Divide its mass by its volume to find the mass per unit volume, or density, of the teaspoon. Check the figures in Table 1 to find whether the teaspoon is made of silver.

Two white powders—alike or different?

Suppose one of your classmates has two jars, each half-full of a white crystalline substance. And suppose you are asked to tell if both jars are filled with the same substance. The only hint you are given is that the stuff in the jars can be bought at the grocery store. The properties you have been studying will help you find out if both jars contain the same substance.

You might want to taste the substances. DON'T! Grocery stores sell sugar, salt, and baking powder that are harmless. But they may also sell ant killers and floor-cleaning materials that are poisonous. **Never taste an unknown chemical!**

Try something simpler—or at least less dangerous. Look closely at the two powders, perhaps with a magnifying lens if one is around (figure 16·4). Do they really look alike? They are both white and seem to have the same shape particles. Do you have enough information to decide whether both jars contain the same substance?

If not, look at figure 16·5 to see what happens when you put a teaspoonful of each substance into water. Do they both dissolve? Are both substances still alike? Do you have enough information now?

16·4 The two powders under a magnifying lens.

16·5 The two powders dissolved in water.

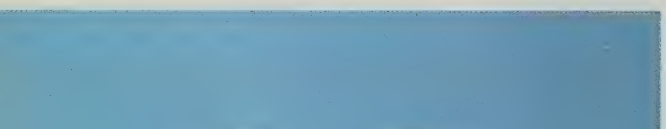
Perhaps you would like to determine the density of both substances to confirm your decision. But it is difficult to get two piles of powder of exactly the same volume. There are always spaces between the grains of powder. It is easier to compare two liquids or identical blocks of two solids. So perhaps you should skip measuring densities this time.

You have examined the color, shape, and solubility of the two powders. Are you ready to say that your classmate filled both jars with the same substance?

Just to be sure, you should try another comparison. Test whether the water solutions of the powders conduct electricity. Look at figure 16·6. What is your conclusion now? It would be a good idea to check further to confirm your findings.

You can check the melting points of the two substances. Each spoon in figure 16·7 contains a small amount of one of the substances. With good equipment you could measure the exact temperature at which each melts. But the demonstration in figure 16·7 will be sufficient for now.

Look at the picture. Does it support the decision you made after looking at figure 16·6?



16·6 The lighted bulb, on the left, indicates that the solution conducts electricity.

16·7 Besides melting, the contents of the spoon on the right has changed color.

16·8 Sulfur is an example of a substance which can occur in several forms. Sulfur occurs in three forms. Two of these are crystalline. The third is noncrystalline. Both crystalline forms are shown here. Note: Neither of the unknown powders in figures 16·4 through 16·7 is sulfur.

You now have five bits of evidence. Three show the powders are alike. Two suggest that they are different. Are you ready to decide now, or do you want to experiment further?

It is much easier to decide that two things are different than to decide they are alike. One measurement, accurately done, that gives two different results for two different substances, shows that they are different. But you have seen three measurements which suggest the substances are alike can always be followed by a fourth measurement that shows a difference. Or perhaps you will not find the difference until the fifth measurement, or the sixth.

The experienced scientist must be able to decide when to stop trying for a proven difference and to accept the decision: alike. He or she will usually determine the melting and boiling points of the substances immediately after having determined that there are no visual differences.

The experienced scientist can rely on previous experience and the knowledge he or she has gained through many years of training. But sometimes one substance can occur in several forms (figure 16·8). Thus the scientist can be misled and stop testing too early.

TEST YOURSELF

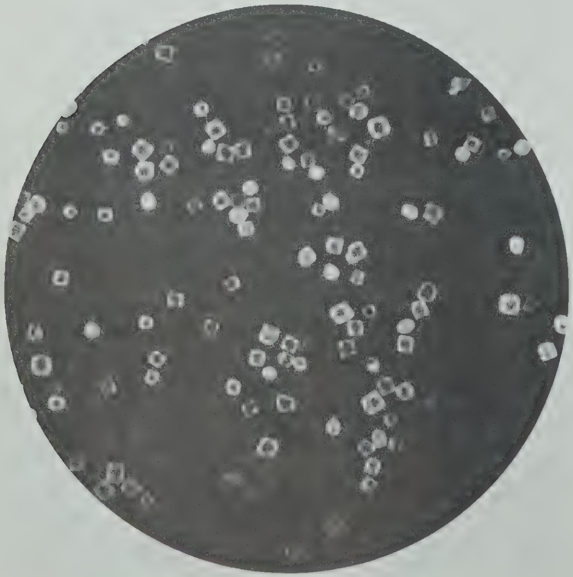
1. *What is a substance?*
2. *Name three things you can do to find out if two substances that look alike are alike or different.*
3. *Make a list of the physical properties that exist for any substance.*
4. *What should you* NEVER *do when trying to identify an unknown chemical?*
5. *Why is it difficult to compare the densities of two powders?*

The procedure you followed in the last section can be used to identify the white crystalline powders. The tests you made determined that they are not the same substance. But you need still more information before you can name the powders.

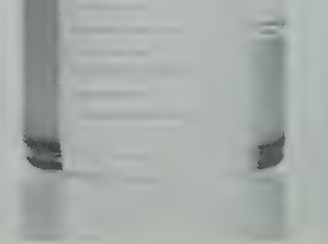
You might look around your grocery store sometime to see how many white powders they sell. Your powders could be any two of them. Of course, many white powders are found other places than on supermarket shelves. Some are used as insecticides and fertilizers. Some are used by doctors and dentists as medicines. Other white powders are used by the highway department to melt ice on roads. And still others are used by industry for manufacturing.

If you were a laboratory scientist trying to identify an unknown white powder, it could be any one of thousands. But your problem is simpler. You know your powders came from the grocery store.

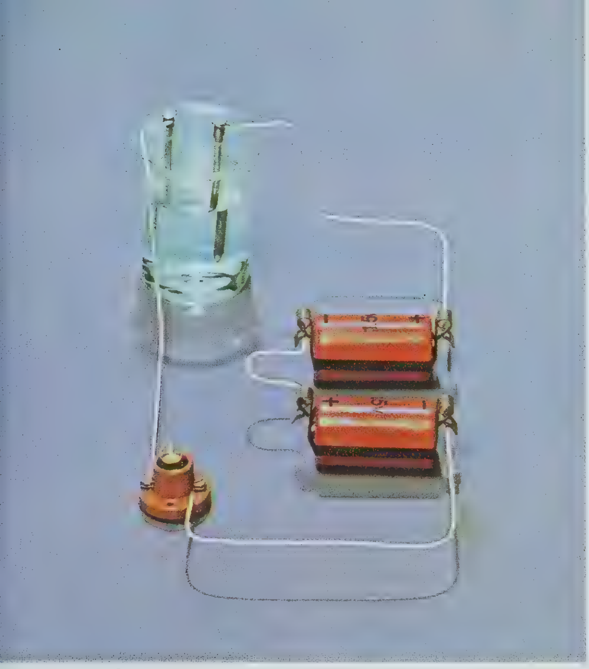
You might have a strong hunch that one of your powders is sugar. **Don't taste!** It could be a soap product—or it could be poison. Instead, think of what you know about sugar. It is a white, crystalline powder that dissolves in water. To compare your sample with sugar, you need to know more (figure 16·9). Does the solution

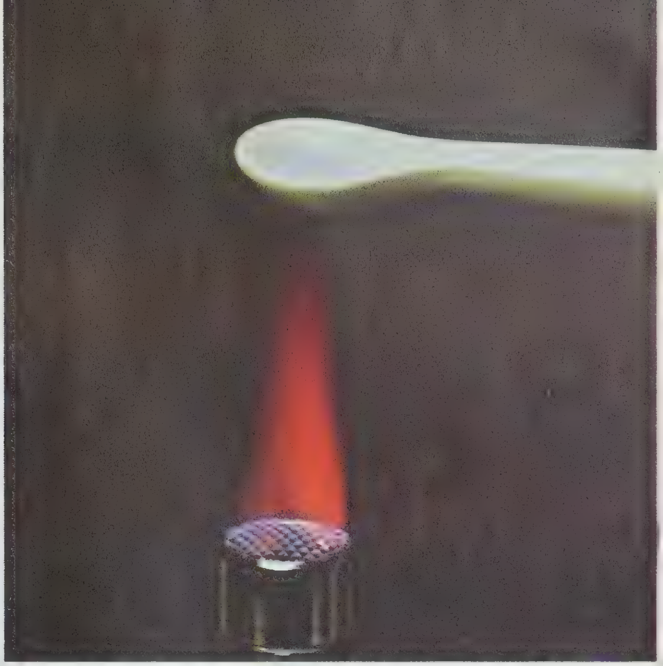


16·9a Unknown powder under magnifying lens.



16·9b Unknown powder dissolved in water.

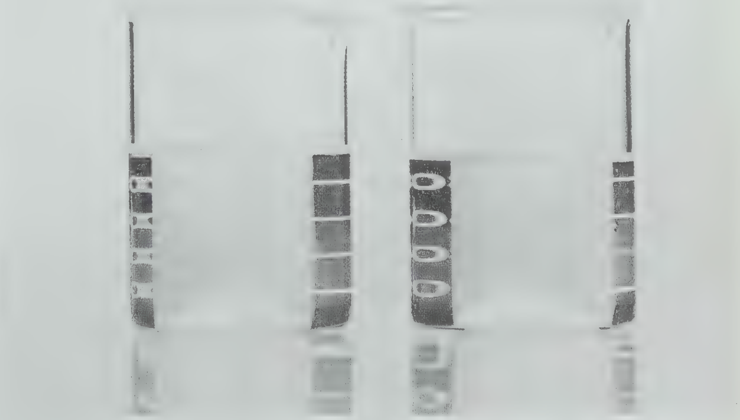

16·9c Solution of unknown powder conducting electricity.


16·9d Unknown powder being heated for the same period of time as the substances in figure 16·7.

of your unknown in water conduct electricity? What happens when you heat it in a spoon? Does it look like sugar under a magnifying lens? (The right-hand substance in figures 16·4–16·7 is sugar.) What happens when you add sugar to alcohol? Does the same thing happen when you add your unknown to alcohol?

You could keep testing the known sample of sugar against your unknown. If your hunch is right, you are in luck. Every test will have the same result for the known sample of sugar and for the unknown white powder.

But what if your hunch is wrong? You could guess again and compare the unknown powder with salt; then with baking powder; then with


16·9e On the left, the unknown powder not dissolving noticeably in alcohol. On the right, the same amount of sugar also not dissolving noticeably in alcohol. Remember, though, that if at least one test indicates that two substances are different, the substances probably are different.

16·10 Chemists use many tables of properties such as this when they are trying to identify an unknown substance. Before using such tables, chemists, and you too, have to use your own observations. In figures 16·4 through 16·7, pages 405–407, the substance on the right is sugar; the one on the left is salt (sodium chloride). Are the results with the unknown powder in figures 16·9a through 16·9d the same as for the sugar or the salt? As another check that you are right—that the powder is salt—look at the table below. Skip past the other substances which contain sodium and go to the bottom line to "chloride." This line gives some properties of sodium chloride. The crystals of the unknown powder are colorless. And they look cubic. We did not check the index of refraction, density, or exact melting or boiling points with our simple tests. But we did see that the powder dissolved in water. It did not dissolve noticeably in alcohol. (By the way, if you have decided that the unknown powder is salt, you are right.)

						Solubility, in grams per 100 milliliters of		
Substance	Crystalline form	Index of refraction	Density	Melting point C	Boiling point C	Hot water	Cold water	Alcohol
SODIUM								
azide	colorless hexagonal		1.846	—	decomposes	40.16		0.314
tetraborate			2.367	741	decomposes at 1575	1.49	8.79	0
bromide	colorless cubic		3.203	755	1390	79.5	121	slight
carbide	white powder		1.575	—	700	decomp.	decomp.	decomp.
carbonate	white powder		2.509	851	decomposes	7.1	45.5	slight
chlorate	colorless cubic or trigonal	1.513	2.490	245-261	decomposes	79	230	slight
chloride	colorless cubic	1.5442	2.165	801	1413	35.7	39.12	slight

baking soda; and so on until you have tried every white powder in the store. That could take you a long time. There has to be a better way to identify the unknown white powder.

Fortunately, scientists have already put together a tool which you can use to identify unknown substances. *Chemists,* scientists who study substances and how substances are changed, have identified the important properties of many substances. And they have put together tables containing lists of substances and their properties.

Figure 16·10 contains information from one of these tables. Some of the more important properties of table salt, called sodium chloride by chemists, are included.

ON YOUR OWN

Testing an advertisement

Is buffered aspirin really more soluble than regular aspirin? You can find out with two glasses of lukewarm water, one of each kind of aspirin, and a clock.

Put a buffered aspirin in one glass of water and a regular aspirin in the other. Be sure that both tablets contain 5 grains of aspirin so that the test is fair. (To find the contents of the tablets, read the description on each label.) Which dissolves first?

TEST YOURSELF

1. *List five physical properties of water.*
2. *Describe the steps you would use to prove that the liquid in a bottle of rubbing alcohol was not water.*
3. *Use figure 16•10 to find the melting point, boiling point, and the density of sodium bromide.*
4. *In what units do you measure density?*
5. *What is the index of refraction of sodium chloride (figure 16•10)?*
6. *What is the density of sugar (Table 1)?*

ON YOUR OWN

More white powders

You can test the physical properties of any of the following white powders that are kept in your home:

Flour
Powdered sugar
Baking soda
Baking powder
Cornstarch
Potato starch
Powdered milk
Salt
Detergent (without bleach)
Soap
Bath dusting powder
Laundry starch

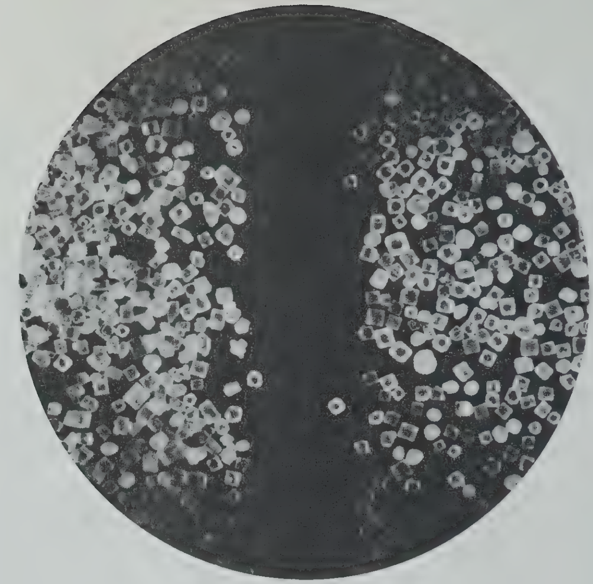
DO NOT test any powders that are not on this list.

Note which of the above powders are soluble in water. Use your simple conductivity tester (page 130) to find which powders conduct electricity while dry or in solution. Find which melt easily in a steel spoon, dissolve in rubbing alcohol, and so forth.

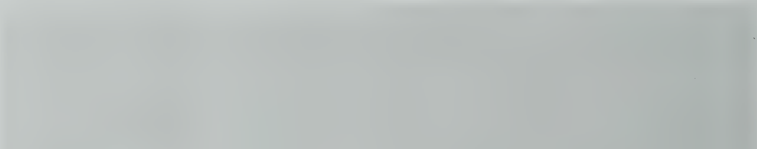
CAUTION: Be sure to use the lowest flame when you try to melt a substance in a steel spoon. Also, hold the steel spoon with a potholder or tongs so that you don't burn your hands.

Your classmate could have played a trick on you when she gave you the two jars of white powder. Instead of giving you two pure substances, she could have given you one pure substance and one mixture of substances. In fact, she could have given you one jar filled with salt and the other filled with a mixture of sugar and salt. At what point could you have decided that the two powders were not exactly alike? Figure 16·11 shows what happens when you test two such powders.

Are the shape and color of the powders different? Do both powders easily dissolve in water? Do the water solutions (1 teaspoonful of powder in 1 glass of water) of both powders conduct electricity? You might accurately measure the electrical resistance of the solutions to try to find a difference.



16·11a The mixture (salt and sugar), on the left, and the pure substance (salt), on the right, look almost the same under a magnifying lens.

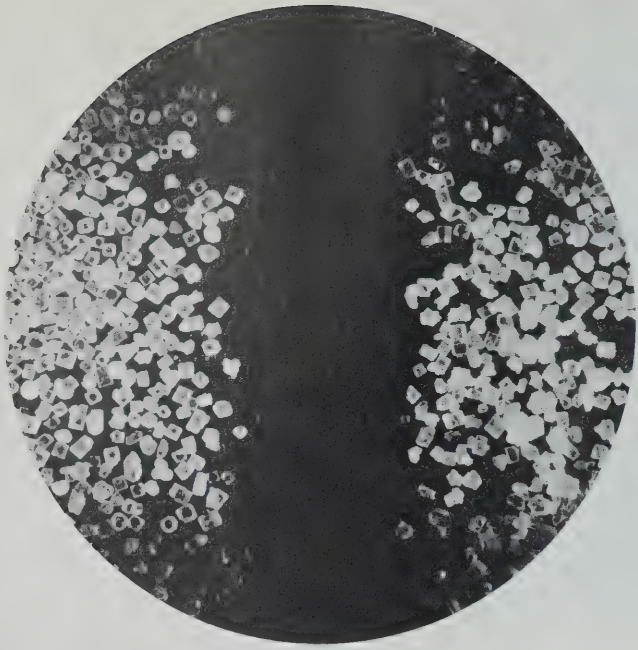


16·11b Both samples dissolve in water.

16·11c Both also conduct electricity.

16·11d One of the samples melts and changes color, but so did pure sugar on page 406.

The plain salt solution is a better conductor than the solution containing an equal mass of the salt-sugar mixture. But your simple conductivity tester is barely sensitive enough to detect the difference. Even the test in which you heat a teaspoon containing each powder over a flame may not be decisive. The salt-sugar mixture can contain so much sugar that you cannot see the salt. Is that the case in figure 16·11?



16·12a Sugar is on the left. A sugar-and-salt mixture is on the right.

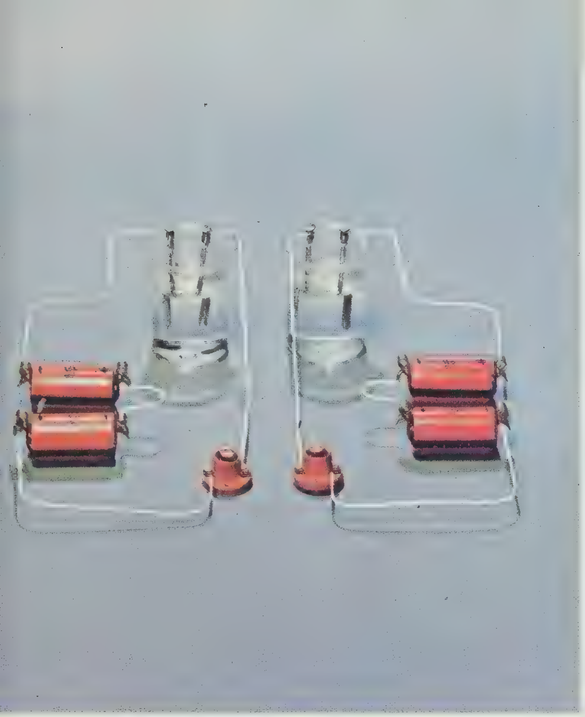
16·12b The two samples dissolved in water.

If the pure substance had been sugar instead of salt, you would have gotten the results shown in figure 16·12. Is there a difference in shape or color of the particles? The solubility? The ability of the solutions to conduct electricity? Think about what happened in figure 16·6. Only one of the solutions conducted electricity. Can you remember which one?

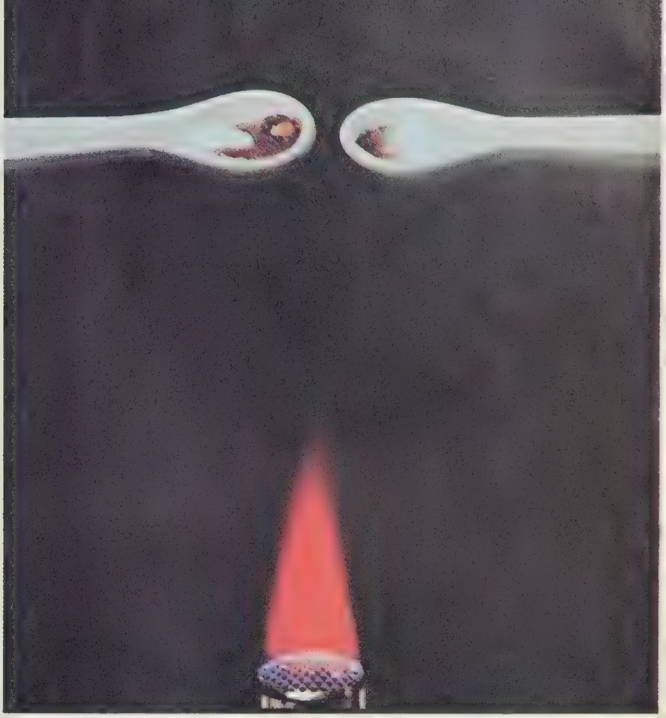
You could not tell by looking at the white powders whether they were pure substances or mixtures of substances. But sometimes it is easy to tell when you have a mixture of substances. There is no problem with a combination of salt and pepper or a mixture of water and oil (figure 16·13).

But would you be willing to say whether oil itself is pure or a mixture? What about water? gasoline? vinegar? air? If these materials are pure, each of them will have its own specific set of physical properties.

Chemists refer to pure materials when they speak of substances. For instance, a



16·12c The mixture conducts electricity slightly.

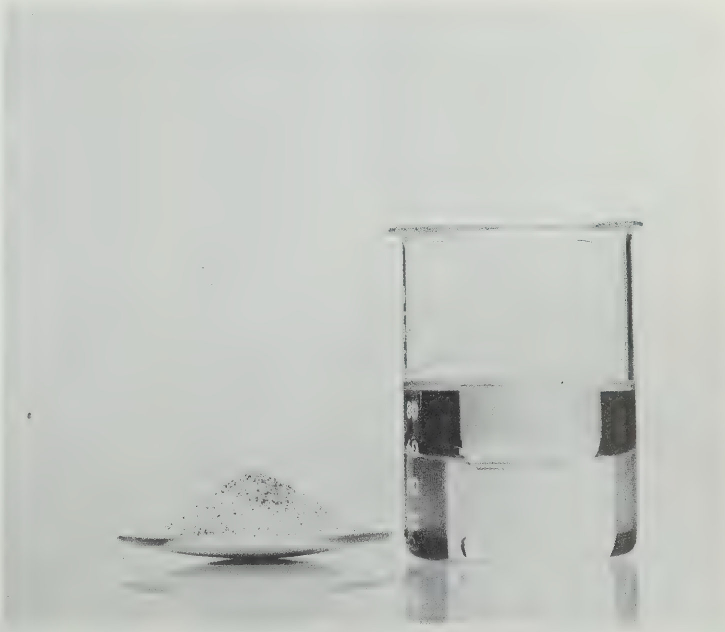


16·12d One sample melts and changes color more than does the other one.

substance always melts completely at the same temperature. But mixtures usually melt over a range of temperatures.

A substance always boils at the same temperature, provided the pressure is not changed. But a mixture of liquids usually boils across a range of temperatures.

The fact is, there are not many pure materials around you. Nearly everything in nature is a mixture and its component substances *must* be separated from each other before they can be identified.



16·13 The grains of salt and pepper remain separate even when they are stirred together. And oil does not dissolve in water. It floats on top of water.

16·14a

Taking apart mixtures

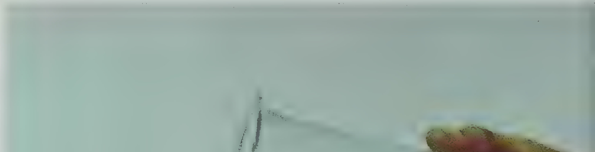
Since most of the materials found in nature are not pure, separating substances from each other is an important part of chemistry. *Chemistry* is the science that deals with the composition of substances, their properties, and how they are made or changed.

Chemists have developed a number of ways to separate the substances in a mixture. They do this to identify unknown substances or to remove useful substances from the mixtures in which they may occur. If you tried to separate vinegar-and-oil salad dressing into its component parts you would use many of those methods.

Look at a bottle of vinegar-and-oil salad dressing. You can tell there are at least three components: two layers of liquid and some solids floating around in them.

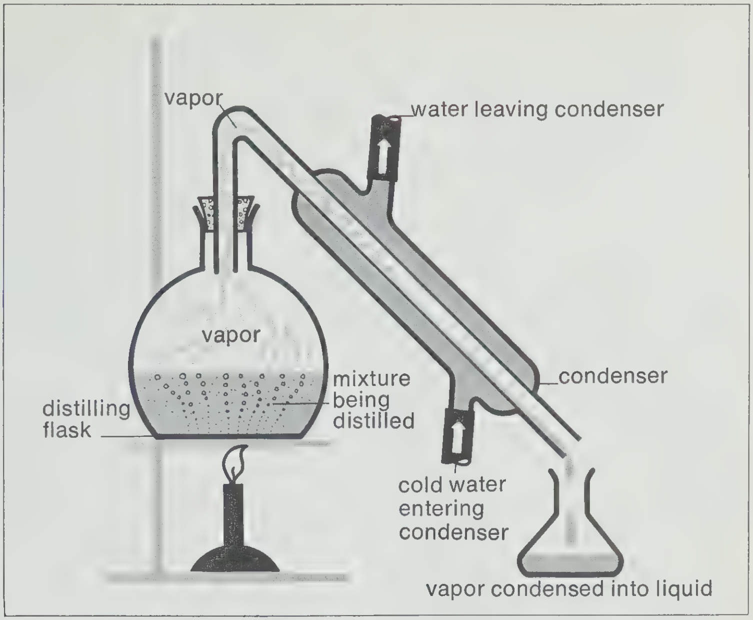
Your first step might be to separate the solids from the liquids. For this you could use

16·14b



16·14c

16·15 Fractional distillation. The lower-boiling substance vaporizes. The vapor rises in the flask and enters the condenser. Cold water running through the outer part of the condenser cools the vapor so it will condense and run into the flask.



a piece of *filter paper,* a specially prepared paper that allows liquids to run through its pores while it catches the solids. In fact, you could separate out the solids by pouring all of the dressing through any kind of strainer that will hold solids back. Do you think the solid material is only one substance? What about the liquid that is left?

To separate the two layers of liquid you can simply pour them very carefully. The less dense top layer will pour off, leaving the denser bottom layer behind. Can you tell which layer is oil and which is vinegar?

Both liquids look pure enough, but in fact they are still mixtures. Each of the liquids has molecules of two or more substances dispersed throughout it. Special mixtures of this type are called *solutions.*

Vinegar is a solution that consists of a flavoring agent called acetic acid dissolved in water. The vinegar probably also contains some salt that was used to flavor the salad dressing. The oil is also a solution of several substances.

The different substances in both the vinegar and the oil can be separated out. The vinegar can be separated by a process that relies on change of state. The process used to separate the substances in the oil also uses change of state. But it is much more complex and requires special equipment. So let's consider only the vinegar.

The first step in separating the substances in vinegar involves removing the water. The boiling point of water is lower than that of acetic acid or salt. So when the vinegar is heated, the water is the first substance to change to the vapor state.

After all the water has boiled away, the acetic acid and any substances dissolved in it are left. Then the acetic acid begins to boil. If the acetic acid vapor touches a cool surface, it *condenses* (returns to the liquid state). In this way it can be drawn off as a pure substance. All that remains is any solid material, probably table salt, that was dissolved in the dressing.

The process of boiling away one part of a mixture at a time, first the one with the lowest boiling point, then the one with the next higher boiling point, and so forth, is called fractional *distillation.*

Distillation is useful because each liquid in a solution vaporizes at its own boiling point and can thus be separated from the other substances in the solution.

You may have used one other process of separating the components of a mixture (Heat Unit, Chapter 15). Instead of boiling away the liquid, you can simply let it evaporate. Any solid that was dissolved in it will fall out of solution and remain behind. This procedure, called *crystallization*, gives very pure solids and, if done carefully, very pretty ones.

TEST YOURSELF

1. *How does the melting point of a pure substance differ from that of a mixture?*
2. *Name three ways of separating the substances in a mixture.*
3. *Which separation method would you use if the mixture were a solution of sugar in water?*

ON YOUR OWN

Separating a mixture

Try to separate the parts of a jar of oil-and-vinegar salad dressing. Use your text as a guide. How many different solids did you find? How many liquids did you find?

16·16 Salt crystals on a watchglass.

Gasoline and Peppermint

16·17 The gushing oil well has become a rare sight. We now have means to prevent oil wells from erupting in this way.

Millions of barrels of petroleum

The petroleum industry distills large volumes of petroleum to make thousands of products, including printing inks, drugs, plastics, synthetic fibers, and gasoline.

Petroleum is a mixture of many different substances containing hydrogen and carbon (*hydrocarbons*). These hydrocarbons have boiling points that are very close together. Therefore special distillation equipment is needed by the petroleum industry. The most important part of this equipment is the fractionating column. It separates the hydrocarbons into groups or *fractions* according to boiling point. This separation is the first step in petroleum refining.

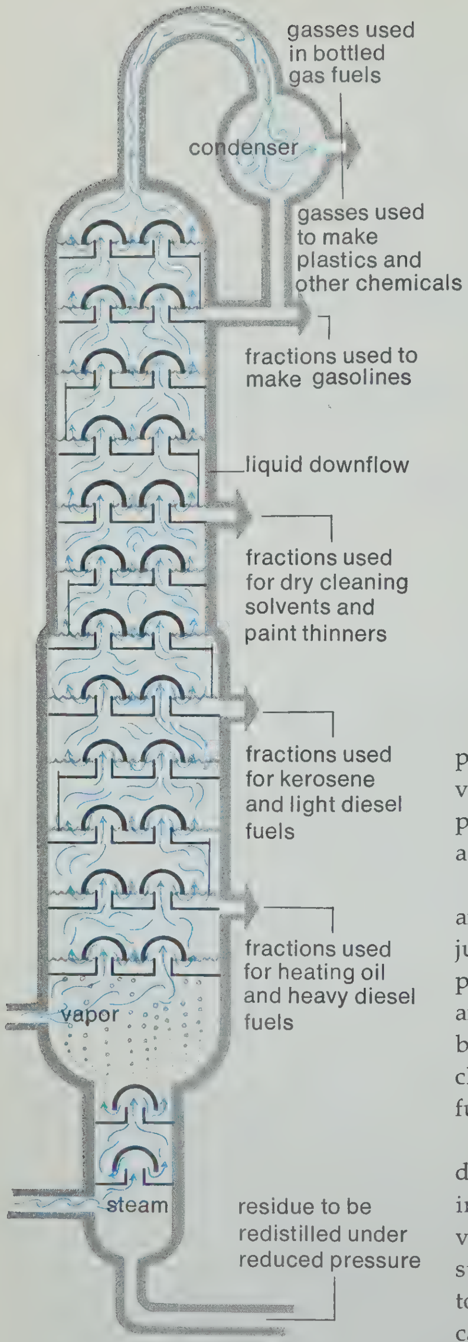
If you have ever driven past an oil refinery, you have probably seen fractionating columns. They are huge metal towers which often stand 30.5 meters (100 feet) high and are 6 meters (20 feet) wide. Outside, each tower is connected to a bewildering network of pipes. Inside, each tower has a series of metal plates arranged like the floors of a building. These plates contain tiny holes so that vapors can pass through.

Crude petroleum, a dark, sticky, foul-smelling liquid, is heated to about 315°C (600°F) in a furnace at the base of the tower. At this temperature most hydrocarbons vaporize. Vapors tend to rise. Sometimes the column itself is heated to help the vapors rise.

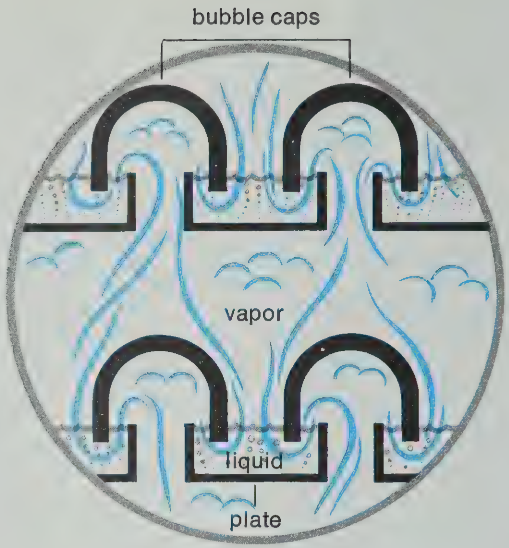
As the vapors rise through holes in the plates, some condense in each plate, forming pools several centimeters deep. You might think that the liquid would drop through the holes. But this is prevented by pressure from the rising vapors. The vapors that do not condense continue upward.

As vapor arrives at a plate, it bubbles upward through the liquid on the plate. An exchange takes place between the bubbles of vapor and the liquid. Some higher-boiling substances in the vapor condense and some lower-boiling substances in the liquid vaporize. This exchange is why a fractionating tower works so well.

The vapors of substances with low boiling points may reach the top plates of the tower before condensing. Vapors of substances boiling in a medium range travel only halfway up. Vapors of the highest-boiling substances condense on the bottom plates.


gasses used in bottled gas fuels
condenser
gasses used to make plastics and other chemicals
fractions used to make gasolines
liquid downflow
fractions used for dry cleaning solvents and paint thinners
fractions used for kerosene and light diesel fuels
fractions used for heating oil and heavy diesel fuels
vapor
steam
residue to be redistilled under reduced pressure

16·18a



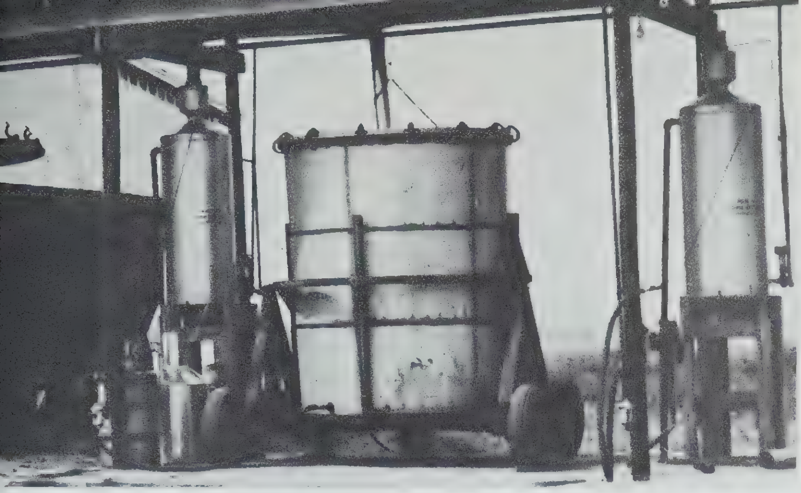
ENLARGED VIEW OF SECTION
IN CENTER OF FRACTIONATING TOWER

16·18b

The fractions of liquid hydrocarbons that have collected on the plates are removed by pipes leading from the side of the tower. The vapors which do not condense come off at the top. These include propane and butane gases, used in bottled-gas fuels, and ethylene and propylene gases, used to make plastics and other chemicals.

The lowest-boiling liquids which condense on the upper plates are treated further to make gasolines. Substances that condense just below the upper plates are used for dry-cleaning solvents and paint thinners. Fractions which condense on the plates below these are used for kerosene and diesel fuel burned by jet planes and buses. And the liquids which condense on the bottom plates include hydrocarbons used for fuel in home oil burners and diesel fuel for trucks.

Material remaining in the bottom of the fractionating column is distilled again under reduced pressure. This process lowers its boiling point. A liquid boils only when it becomes hot enough to form vapor by overcoming the pressure of the atmosphere against its surface. When atmospheric pressure is reduced, less heat is needed to boil a liquid. This low-pressure distillation separates the hydrocarbons used for lubricating oils. The portion of the petroleum which does not boil is treated to obtain asphalt used for floor tiles, roofing, and paving roads.



16·19

Using steam to distill peppermint oil

Another way to distill a substance at a temperature below its boiling point is to pass steam through it. This works because the steam mixes with the vapors of the substance. The pressure of the steam-vapor mixture overcomes the pressure of the atmosphere at a lower temperature than would the vapor pressure of the substance alone. In this way vapors of the substance being distilled escape at a lower temperature.

Steam is used in distilling peppermint flavoring for items such as chewing gum, candy, and toothpaste. The boiling range of the liquid mixture that makes up peppermint oil is 150°C to 300°C (300°F to 570°F). Such temperatures can cause changes in the oil that ruin its flavor. By using steam, the oil can be distilled at temperatures below 100°C.

In the United States, peppermint oil comes from a plant grown mostly in Washington and Oregon. The oil is distilled in the fields. First the plants are cut and allowed to dry for several days. Then they are chopped to help release oils from the leaves. Next they are put into large steel containers mounted on trucks. The trucks are driven to a nearby field and connected to a steam source and condenser which are set up under a shed (figure 16·19).

As steam is passed through the cut-up peppermint leaves, heat causes the oil to vaporize. Then the mixture of steam and oil vapors travels to the condenser where both become liquid again. Because the oil is lighter than water and is not soluble, it rises to the top and forms a separate layer which can be drawn off. Peppermint leaves yield about 1 percent of their weight as oil, depending on how dry they are.

Peppermint oil is a mixture of many different substances. Usually they are not separated because each contributes something to the pleasant taste.

Crystallization in industry

From Aspirin To Fake Gems

Thousands of tiny crystals

Crystallization is often used to purify products such as table salt, sugar, and aspirin. For example, aspirin is formed by a chemical reaction that takes place in a hot solution. When the reaction is complete, both aspirin and impurities are in the solution. The aspirin is less soluble than the impurities. So fine white crystals of aspirin form first when the solution is cooled. But the impurities, which are more soluble, remain dissolved in the solution. The pure aspirin crystals are removed from the solution by filtering. Then they are washed and dried.

Crystallization is also important to the production of other useful things. One such thing is glass cookware that can be taken from the freezer and placed in the oven (figure 16·21). This type of glass, called ceramic glass, has almost the same ingredients as brittle window glass. The difference is that almost 80 percent of the cookware is made up of crystals. Ordinary glass is not.

Manufacturers of cookware glass help it crystallize. In window-glass making the situation is exactly opposite. Glassmakers do not want transparent glass to crystallize. If it does, the glass will become cloudy. If only one or two tiny crystals form, the rest of the glass crystallizes rather quickly. Luckily, however, those first few glass crystals do not form readily without help.

To make a strong, heat-resistant glass such as that used in ceramic glass cookware, glassmakers must add a substance called a nucleating agent to the glass. This substance acts as a starting point for glass crystals to grow on, much as a grain of sand acts as the starting point of a pearl in an oyster. In one ceramic glass called Pyroceram, the nucleating agent is titanium oxide.

The titanium oxide nucleating agent is added to the other substances used to make glass. This mixture is heated to about 1600°C (2900°F). At this temperature the nucleating agent dissolves in the molten glass. The molten glass is then cast into the desired form (such as a dish) and cooled to about 800°C (1500°F). The mixture is no longer molten at this point, and the glass is frozen in its usual noncrystalline form. But the titanium oxide begins to crystallize, forming fine nucleating particles.

16·21 Ceramic glass cookware can withstand this kind of treatment.

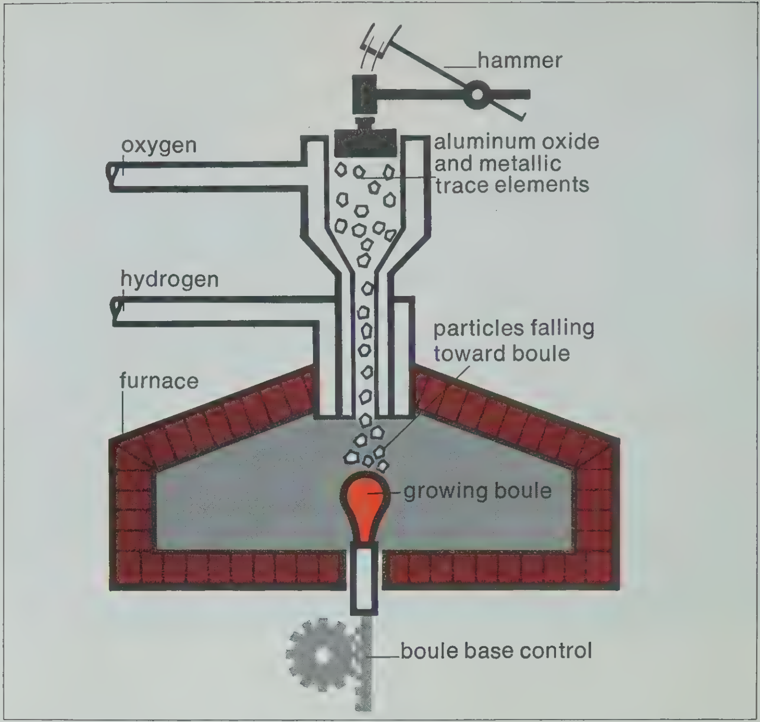
After about an hour at 800°C, the temperature of the glass is raised to the point where glass softens. But now, with the very fine titanium oxide particles suspended through it, the glass begins slowly to crystallize. This temperature is held for about four hours so that as much of the glass as possible will crystallize.

Large single crystals

Under proper conditions, a pure liquid can be made to form large single crystals rather than thousands of tiny crystals. Some of the large single crystals are valued for their beauty. These include precious gems used in jewelry. Others are valued for their durability and are used for phonograph needles and bearings in watches and other instruments.

Single crystals of both rubies and sapphires are made of alumina, a mineral made of aluminum and oxygen. Pure crystals of alumina are colorless. But small amounts of impurities produce the typical gem colors. For example, a trace of chromium oxide in the alumina makes blood-red rubies, and a trace of titanium oxide and iron oxide in the alumina makes deep-blue sapphires. Other mineral impurities are used to make yellow, purple, and pale-blue stones.

The process used today for making these crystals was developed by a French chemist, Victor Verneuil (ver′noi′), in 1902. In the Verneuil process, alumina powder mixed with the desired impurity is placed in a container with a screen mesh bottom. The powder is


hammer
oxygen
aluminum oxide and metallic trace elements
hydrogen
particles falling toward boule
furnace
growing boule
boule base control

16·22

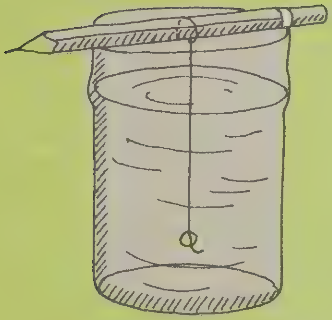
slowly sifted into a hot flame by tapping the container with a small hammer. The flame, produced by a hydrogen-oxygen burner, gives a temperature of over 2000°C (3700°F). The powder melts as it falls through the flame and flows in droplets onto a heat-resistant ceramic base.

A tiny crystal of aluminum oxide on this base acts as a seed to start the crystal. As the molten alumina cools, it freezes in layers on the seed crystal. Soon the crystal begins to grow upward and the ceramic base is lowered to give it room (figure 16·22). At first, the crystal is kept about as thin as a match stick. But when it is about 6 millimeters long, powder is added more rapidly and the flame is regulated to make the crystal wider. The rough gem now looks like a mushroom, with a wide cap on a thin stem.

Growth is continued at the faster rate, forming a single cylindrical crystal, called a *boule* (bül), from the French word for ball—the shape of Verneuil's first gems. After the boule is complete, it is removed from the base and shaped by cutting or grinding.

Synthetic gemstones are chemically identical to natural ones. They are just as beautiful and just as hard. They differ from natural gems in minor aspects of structure which are visible only under a microscope.

ON YOUR OWN



Rock candy

Cause a physical change. Make a batch of rock candy with these materials:

1 water glass
1 small pan
1 pencil or stick
1 spoon
Granulated sugar
String
Water

Boil about a cup of water in the pan. While it is heating, put a cup of sugar into the water glass.

Stir as you slowly pour the boiling water into the sugar. Be careful not to add any more water than is needed to dissolve all of the sugar.

Tie a knot at the bottom of a piece of string. Suspend the string in the glass as shown. Let the liquid stand for several days.

As the water evaporates, sugar crystals will form and climb up the string. These crystals are rock candy.

Chapter 17: Changing Substances

17

Peanut brittle is nothing but sugar with peanuts in it. Or is it?

Something happens to the sugar when you heat it to make the peanut brittle. It becomes a light brown syrup to which you add the peanuts. Then it hardens into a shiny, brown, hard candy. And it doesn't taste the same.

When you melt the sugar you make it into a mixture of sugar and some new substances that formed from heating the sugar. If you keep heating the melted sugar, you can change all of it into new substances. And if you heat those long enough, only a black mass will be left. This is what happens every time you burn some food.

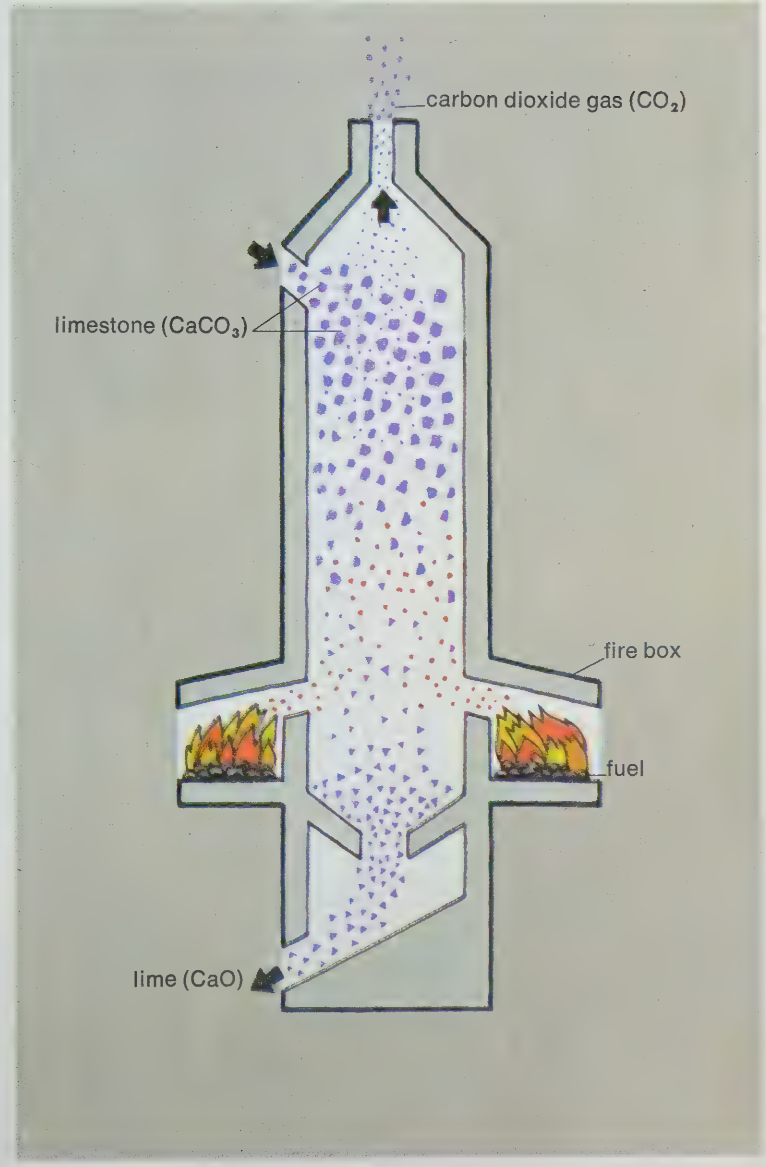
The change that has occurred is not the same as the change when you dissolve sugar in some water. And it is not the same as the change when you melt salt in a spoon.

When the water evaporates, the sugar that was dissolved in it will be left behind. When the spoon cools, the salt in it will return to the solid state. But you can't get the sugar back from the black mass left in the pan. It is no longer sugar. It is a different substance. The change in the sugar is a *chemical change,* the change of one substance into another.

Sugar is not the only substance that *decomposes*, or breaks down, into other substances when it is heated. Limestone, a common mineral, also decomposes when it is heated. It decomposes into carbon dioxide gas and calcium oxide.

The decomposition of limestone is very important to the building industry. The calcium oxide formed is used in the manufacture of mortar and of plaster.

Decomposition on heating is only one kind of chemical change or *reaction*. The chemical changes or reactions in which a substance takes part are the *chemical properties* of that substance.



17·1 Limestone furnace used in the manufacture of calcium oxide (lime) for the construction industry.

An important chemical property of many substances is the ability to react with the oxygen in the air. Figure 17·2a shows a piece of the element phosphorus in air. Most substances do not react as rapidly or as violently as white phosphorus. Think about what happens to a piece of steel wool when it stands in air for a long time —especially if the steel wool is moist (figure 17·2b).

Aluminum also reacts with the oxygen in the air. The reaction is hard to see because a thin coating is formed. The coating protects the aluminum from further reaction. This coating has been removed from the shiny side of the bar in figure 17·2b.

Another kind of chemical reaction is taking place in figure 17·3a. Small pieces of the element zinc have been added to water containing a substance called an acid. Notice the bubbles rising in the test tube.

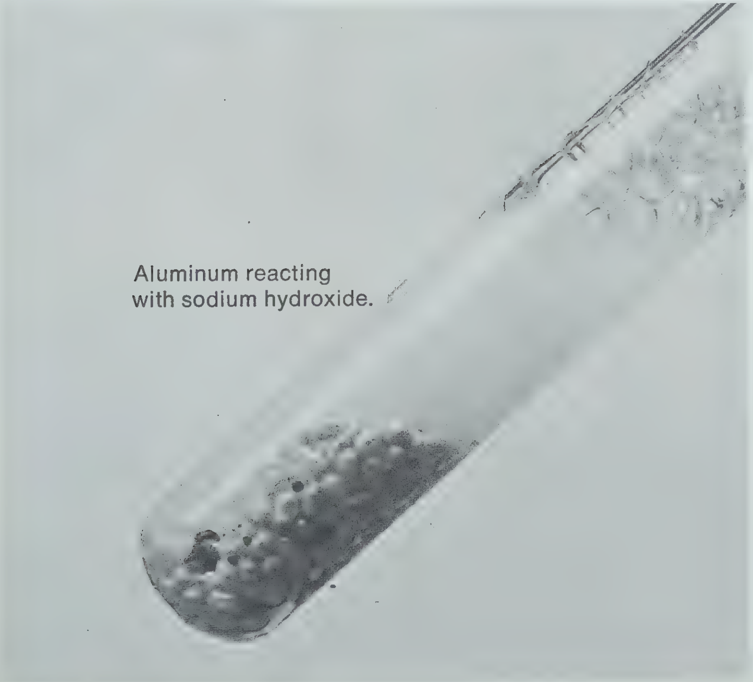
Bubbles are also rising in the test tube in figure 17·3b. Another kind of chemical reaction is taking place there.

17·2a

17·2b

Zinc reacting with hydrochloric acid.

17·3a



Aluminum reacting with sodium hydroxide.

17·3b

Pieces of aluminum have been added to a solution of another substance that takes part in many chemical reactions. It is called an alkali or a base. Reaction in the presence of acids and/or bases is another very common chemical property of substances.

TEST YOURSELF

1. *What is a chemical change?*
2. *Give three examples of chemical change.*
3. *Name two chemical properties of aluminum.*
4. *Name a chemical property of sugar and of limestone.*

ON YOUR OWN

Syrup for pancakes

You can make some syrup by decomposing granulated sugar. Put about a cup of sugar into a heavy frying pan. Place the pan over low heat and stir constantly. The sugar will become a golden brown syrup. Take the pan away from the heat and use the syrup. This chemical reaction has a tasty result.

Some evidence of chemical change

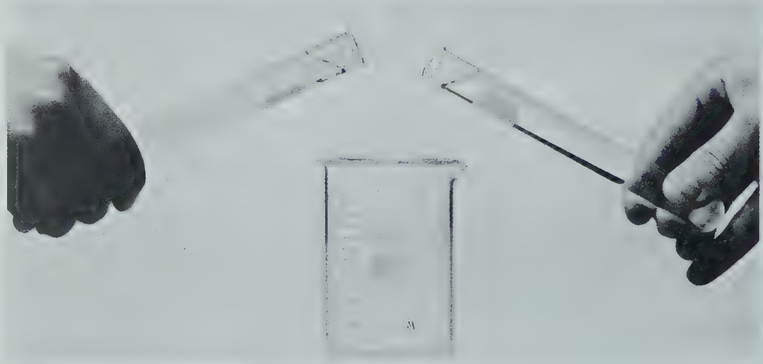
When you looked at the pictures in the last section, could you always tell if a chemical reaction was taking place? Were you always sure that a new substance was being formed? You can be sure that a chemical change is taking place when you see a fire. For example, you probably do not doubt that there is a chemical reaction between air and burning steel wool (figure 17·4).

When the same change occurs slowly, as it does between cold steel wool and air, you may not see it. Then, months later, you may notice that some rust has formed. The chemical reaction has taken place slowly. Chemical reactions can take place rapidly or slowly, but rapid reactions are more obvious.

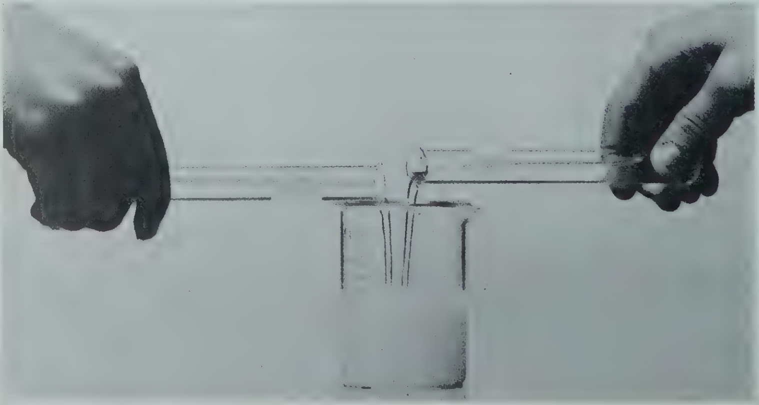
The production of a gas is often a sign that a chemical reaction is under way. You look for a reaction when you see bubbles. You saw bubbles in the reactions with an acid and a base (figure 17·3).

A color change is another sign that a chemical reaction is taking place. The sugar became a brown mass when it was heated (figure 16·7, page 406).

17·4



17·5a



17·5b

Figure 17·5 shows still another sign of a chemical reaction. Two clear solutions have combined, yet a solid substance is in the beaker. A new substance has been formed. It is not soluble although the substances that reacted to form it were soluble. The formation of a solid substance from a reaction between two solutions is called *precipitation.* The solid substance formed is a *precipitate.*

ON YOUR OWN

Household chemistry

You can investigate some reactions with acids and alkalis using these common substances:

Vinegar
Household ammonia (without any additives)
Steel wool, uncoated
Paper clip
1 strand of copper wire
Hair pin, uncoated
Bobby pin, uncoated
Needle
Straight pin
Aluminum foil
Top of tin can
Pull ring of pop-top can

Gently heat about 1 cup of vinegar in an aluminum or ceramic glass pan for a few minutes. Pour about half of the hot vinegar into a small, clear glass. Put the rest aside to be added to the vinegar in the glass after each reaction. That way, there will always be enough vinegar in the glass for a reaction to take place.

Put a piece of steel wool into the vinegar. Is there any sign of a chemical reaction? If so, quickly remove the steel wool. If not, wait a minute or two to find out if there will be a reaction. Then remove the steel wool and repeat the experiment with another item on the list.

Every time you see signs of a reaction, quickly remove the metal from the vinegar.

Continue the experiment, using as many of the items listed as you like. Try any other metal items that you can think of.

DO NOT add any household chemicals to the hot vinegar. The reactions that would take place in some cases can be extremely dangerous and can injure you.

Put some household ammonia in another small, clear glass. Do *not* heat the ammonia. Use it carefully. Follow the directions printed on the ammonia container.

Take a piece of steel wool that has *not* been in contact with the vinegar and place it in the ammonia. Note if there has been any sign of a reaction, just as you did with the vinegar.

Try the experiment with any of the items you tried in the hot vinegar. BUT be sure that there is no trace of vinegar on any of the items you put into the ammonia.

Which items reacted with the acid, vinegar? Which ones reacted with the alkali, ammonia?

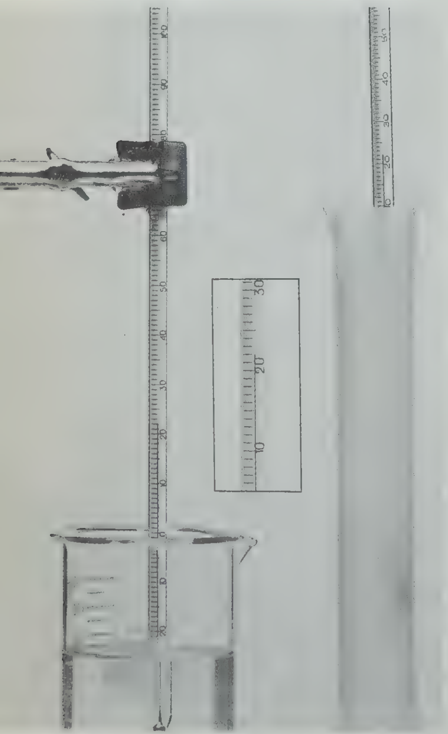
Energy and chemical reactions

Each of the chemical reactions you have seen is accompanied by a change in energy. In fact, every chemical reaction is accompanied by a change in energy. Thus the production of heat is one sign of a chemical reaction. The burning of gasoline in the automobile engine is a chemical reaction. So is the burning of coal in an electric power station. And so is the burning of gas on a gas stove.

The amount of heat given off in other chemical reactions is less dramatic. In figure 17·6 some household ammonia has been carefully mixed with vinegar. Is a chemical reaction taking place?

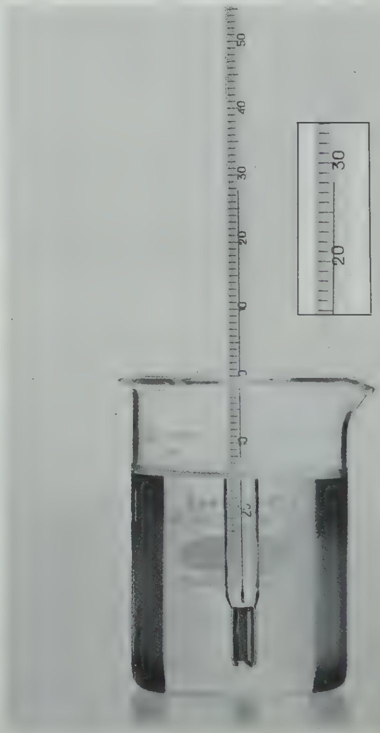
Now look at figure 17·7. The glass contains a teaspoon of baking soda (sodium bicarbonate) mixed in water. Notice what happens to the temperature when the vinegar is added to the solution. If you think the result is strange, you might want to try this experiment yourself. You will feel the change in temperature if you put your hands around the glass.

Not all chemical reactions produce heat. Some reactions absorb heat from the air, from the liquid in which the reaction takes place, or from any place where heat is available.



17·6a

17·6b



17·6c

The energy changes that accompany every chemical reaction can be put to work. The chemical energy can be changed to heat energy, to energy of motion, or to electrical energy.

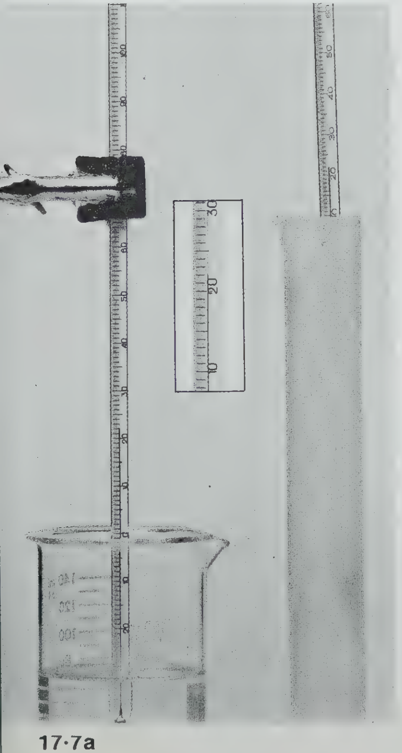
For instance, the explosive reaction between gasoline and air in the automobile engine releases much heat. That heat is supplied to the gases formed in the reaction. The gases expand and push the cylinders which move the car.

Another useful reaction is the one which takes place between coal and air. In an electrical power plant, the heat produced by this reaction is used to change water into the steam that drives the turbine that runs the electricity generator.

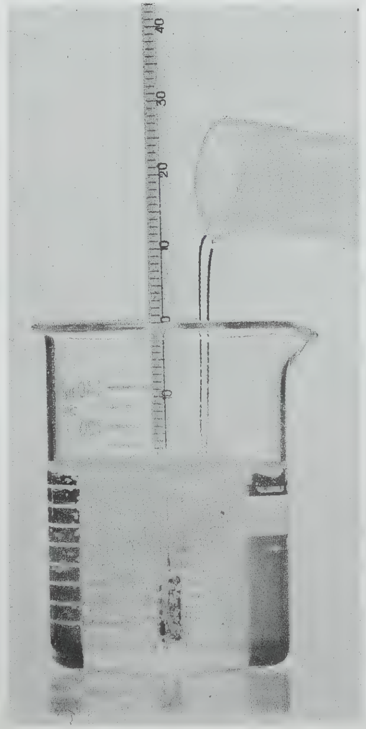
ON YOUR OWN

Reaction signs

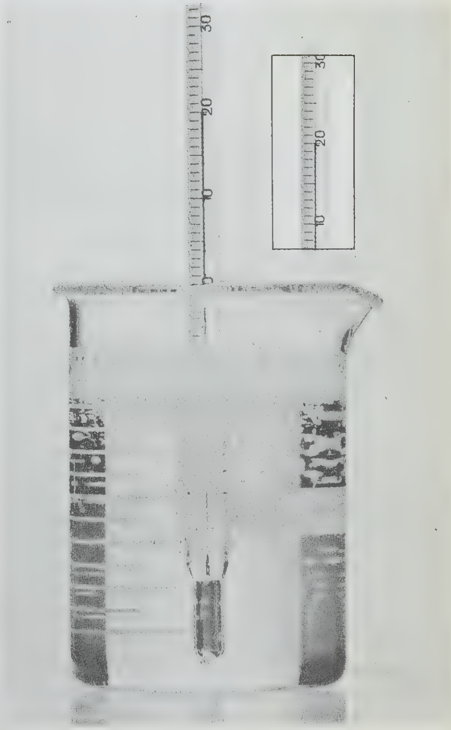
Look around you for signs that a chemical reaction has taken place. Where can you see signs of a reaction with the oxygen in the air? Where can you see signs of a reaction in which new substances have been made? Are any decomposition reactions taking place around you? What about reactions with acids and alkalis?



17·7a



17·7b



17·7c

Changing the speed of a chemical reaction

Have you noticed a change in the speed of certain chemical reactions when there is a change in the temperature? When sugar in a pan is heated slowly, it becomes a brown liquid. When it is heated rapidly, it very quickly becomes a black mass.

It takes a long time for cold steel wool to react with the air. But hot steel wool reacts very quickly. And think about how long you can keep a piece of raw meat in the freezer without its changing. It would spoil if you left it on the table for a much shorter time. And it changes completely in a very short time when you cook it.

Adding heat has made all of the above reactions take place more rapidly.

The pad of steel wool that you saw reacting rapidly with air (figure 17·4) is made mostly of iron. If you were to hold an iron nail in a flame, the nail would not burn. Notice the difference between the steel wool and the iron nail (figure 17·8). This same sort of difference exists between wood chips and a whole log. It is easier to start a campfire with twigs or wood chips.

The surface area of the reacting substances has an effect on the speed at which a chemical reaction takes place.

Other factors also affect the speed of a chemical reaction. In figure 17·9 there are two test tubes. One tube contains an acid solution and the other contains two drops of that acid solution in 40 drops of water. That is, the acid solution in the second test tube is only 1/20 as strong as the acid solution in the first one. There is some iron shot in the bottom of each test tube. Compare the effect of the strong acid solution with that of the weak acid solution.

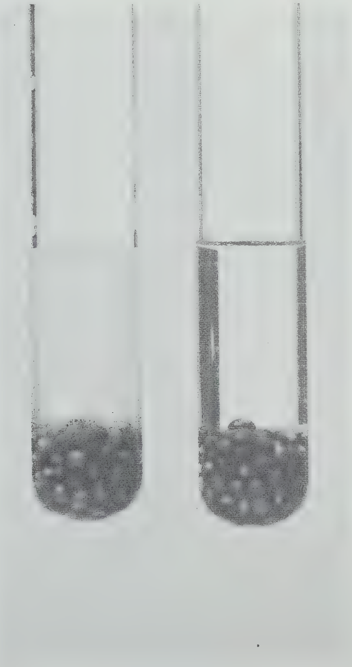
Notice what happens when you reduce the concentration of one substance in a chemical reaction. How will you affect the speed of a reaction if you increase the concentration of the reacting substances?

17·8

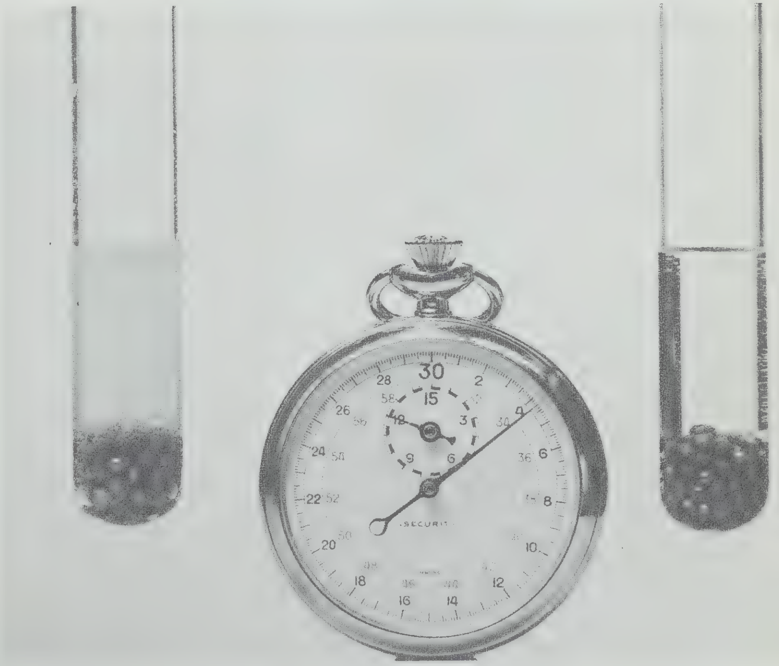
There is still another way to speed up the reaction between two substances. If pure hydrogen gas is mixed with pure oxygen gas at normal temperatures, nothing seems to happen. In time, the two gases will slowly react to form water. But it will take years. If the mixture were ignited, it would explode and form water in an instant. However, this is a very dangerous experiment and has cost some people their lives.

There is a less dangerous way to speed up the same reaction. A small amount of powdered platinum can be added to the mixture. The reaction will take place less explosively than if the mixture had been ignited. But it will take place more rapidly than it would without the powder. Water is the product of the reaction, and the powdered platinum can be recovered unchanged.

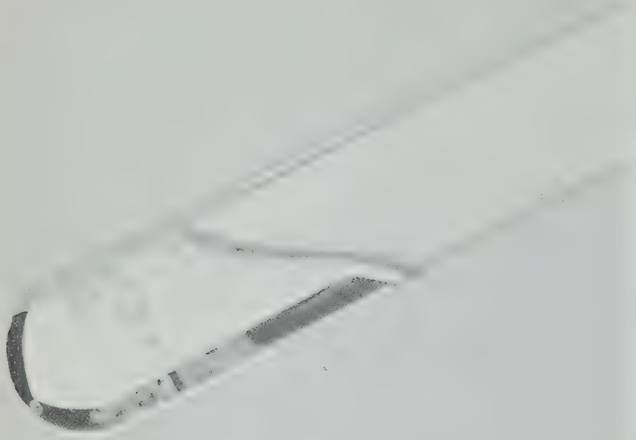
The same sort of thing happens when you add a powdered substance called manganese dioxide to a hydrogen peroxide solution. Hydrogen peroxide is a common household antiseptic. It decomposes slowly at room temperature, forming water and oxygen gas.



17·9a A strong acid solution (left) and a weak acid solution (right) have just been added to the iron shot in the test tubes.

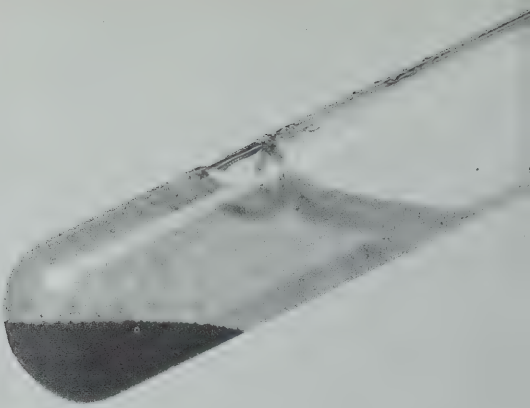


17·9b The stopwatch shows how much time has passed since the acid was added to each of the test tubes. Can you see any signs of a reaction in the tube containing the weak acid?



Hydrogen peroxide solution slowly decomposes in air.

17·10a



Adding a manganese dioxide catalyst speeds up the decomposition of hydrogen peroxide.

17·10b

This decomposition takes place without manganese dioxide or anything else having been added to the hydrogen peroxide. In time, a bottle of hydrogen peroxide will lose its effectiveness as a result of this decomposition.

When manganese dioxide is added to the hydrogen peroxide solution, the decomposition is speeded up. You can see the oxygen bubbling out. During this whole process of the speeded up decomposition, the manganese dioxide is unchanged (figure 17·10).

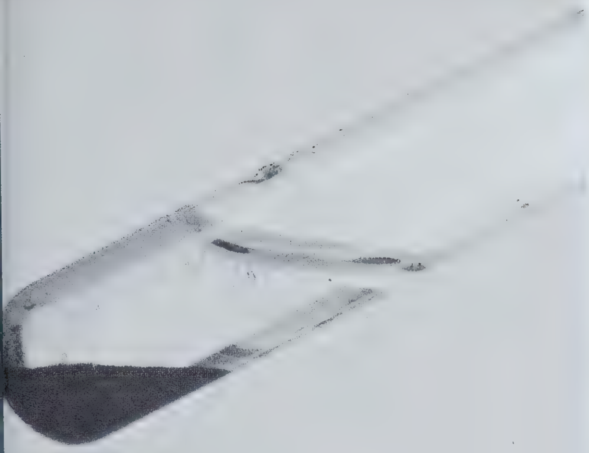
Substances that change the speed of chemical reactions without changing chemically themselves are called *catalysts.* Catalysts used in industry make possible the production of nearly every useful chemical material. Without catalysts, many reactions would just take too long. Or they would require conditions of temperature, pressure, or concentration that would make them expensive and/or dangerous.

Catalysts in your own body, called *enzymes,* control the speed of chemical reactions that keep you alive and growing. The enzymes speed up certain reactions at the right time. In fact, enzymes control the chemical reactions in your body so they follow one another in the proper order.

One enzyme in the blood works the same way as manganese dioxide. It speeds up the decomposition of hydrogen peroxide. (That's why hydrogen peroxide fizzes when you pour it on an open cut or sore.) The presence of this enzyme, called peroxidase, provides the police with a means of identifying dried samples of blood.

TEST YOURSELF

1. *Name three things you might observe that would show a chemical reaction was taking place.*
2. *Give two examples to illustrate the statement that every chemical reaction is accompanied by a change in energy.*
3. *State three factors that might speed up chemical reactions.*
4. *What happens to a catalyst in a chemical reaction?*
5. *What does an enzyme do?*



Manganese dioxide and water remain after most of the hydrogen peroxide has decomposed.

17·10c

ON YOUR OWN

More on that advertisement

In the last chapter, you tested the solubility of aspirin and buffered aspirin in water. But your stomach does not contain water. It contains a dilute acid.

Does buffered aspirin disappear more rapidly than regular aspirin when you put it in a dilute acid? You can find out with two glasses of room-temperature vinegar, one of each kind of aspirin, and a clock.

Put a buffered aspirin in one glass of vinegar and a regular aspirin in the other Be sure that both tablets contain 5 grains of aspirin so that the test is fair. That information should be on the bottle label.

Which tablet dissolves first?

ON YOUR OWN

Testing reaction speed

You can do an experiment on reaction speed with the following materials:

- Steel wool, uncoated
- Water
- Vinegar
- 8 small water glasses
- Thermometer

Heat some vinegar until it is about 70°C. While it is heating, line up the glasses on the table and number them 1 to 8.

Pour hot water from the tap into glass number 1 and room-temperature water into 2. Fill 4 and 6 with room-temperature vinegar. Fill 8 with half vinegar and half water at room temperature. Pour the hot vinegar into 3 and 5. And fill 7 with half hot water and half hot vinegar.

Roll two pieces of steel wool into tight balls so that they have very little surface area. Tear off 6 other pieces of steel wool, all about the same size. Put plain steel wool in the first four glasses, the balls in 5 and 6, and plain steel wool in 7 and 8.

In which glasses does a reaction take place first? In which ones is there a reaction after a while? And in which ones is there no reaction?

What three factors have affected the speed of your chemical reactions?

A model of chemical reactions

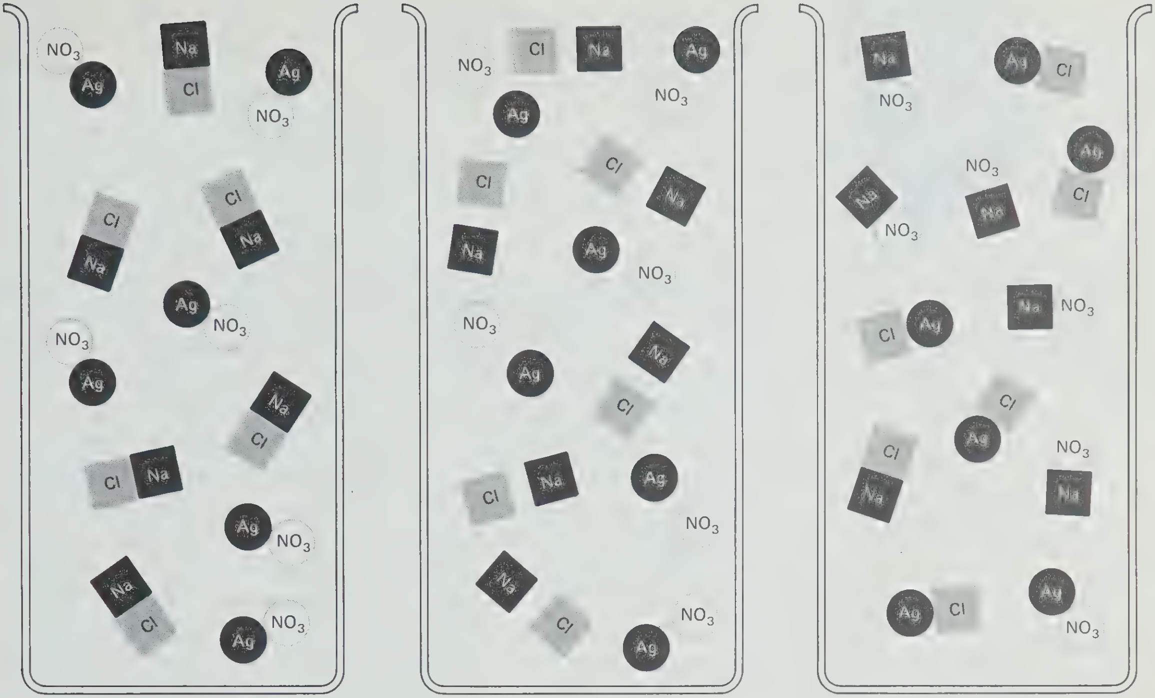
A Molecular Demolition Derby

The model of molecules in motion (Unit 4, page 390) can be extended to explain chemical reactions. The model describes matter as billions upon billions of little particles called molecules, all in constant motion. But what do constantly moving molecules have to do with a chemical reaction?

Think of the molecules as if they were the cars in a demolition derby. Like the cars, the molecules are made up of different parts. Also like the cars, the molecules move around and sometimes bump into each other.

Some of the crashes are gentle. Little happens to the cars. Nothing happens to the molecules. But sometimes the crashes are violent. The cars get demolished, shaken apart into pieces. So do the molecules.

The similarity stops here. A demolished car does not fix itself. But the pieces of molecules "fix" themselves by combining again—in new ways—and thus a chemical reaction takes place. A chemical reaction occurs when the crash between two molecules shakes them apart into fragments, and the fragments then combine in a new way—and form molecules of different substances.



17·12 Molecules of sodium chloride and silver nitrate bump into each other and break apart. When they bump again and recombine, new substances are formed.

Now you can see how temperature affects the speed of a chemical reaction. Increasing the temperature makes the molecules move faster. There are more crashes, and more violent ones, between the rapidly moving molecules. Thus, more molecules get shaken apart.

You can also see why dividing the materials into smaller bits affects the speed of a reaction. Smaller particles, like the wood chips or thin strands of steel wool, have more molecules exposed for reaction. So there are more crashes, and a faster reaction.

Increasing the concentration of the reacting substances has the same effect. The more molecules of the reacting substance that are present in the solution, the more crashes occur. And the faster the reaction takes place.

But, how do catalysts act? In a way they are like traffic signals—broken ones with green lights in both directions. Instead of keeping the speeding molecules apart, the catalysts bring them together. Perhaps a broken railroad switch is a better example. The catalyst pulls the molecules together until they collide as if they were trains switched onto the same track.

This demolition-derby model is a very simple way to look at how substances like sugar split into others (page 443) and how substances like hydrogen and oxygen form new ones like water. The finer points are a part of the story of the atom.

An historical overview of atomic theory

The Story of the Atom Part 1

In the sixth century B.C., Pythagoras, a Greek mathematician and scientist, taught that matter was composed of earth, water, air, and fire. He felt that these existed in various mixtures with the qualities hot, cold, wet, and dry. Pythagoras' ideas were modified by a series of philosophers in the years that followed.

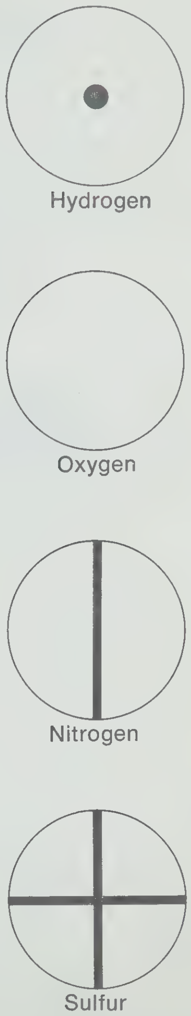
The views that finally came to be accepted were those of Aristotle (384–322 B.C.), one of the most famous of the Greek philosophers. He believed that all space was filled with some basic stuff called hyle. And the four basic elements—earth, water, air, and fire—were absorbed by the hyle in various proportions.

Aristotle thought that all worldly substances were made of different mixtures of the elements in the hyle. And he thought the heavens were made of a fifth element, aether (ē′thər). For the heavens, obviously, were made of a pure substance unlike anything on earth.

According to Aristotle, even the simple substances could be divided into smaller and smaller particles without changing them. He did not believe empty space could exist. But the followers of another Greek philosopher, Democritus (460–380 B.C.), did not agree.

17·13 Modern interpretation of the four basic elements—fire, water, air, and earth.

17·14 Dalton's symbols for some elements.



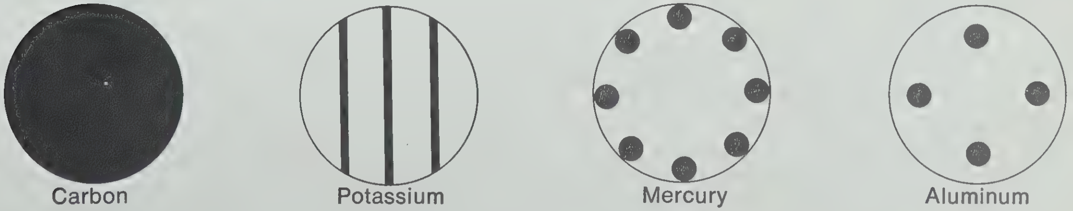
Democritus thought there would finally be one particle of a substance that could no longer be divided. He called that invisible, indestructible particle an *atom*, from the Greek word *a-tomos*, meaning "not divisible." Democritus felt there were different kinds of atoms to make up the different basic substances, or *elements*. He also believed that there were substances made of more than one kind of atom. But Aristotle's views were accepted rather than those of Democritus until the turn of the seventeenth century.

The ideas of Democritus were lost to scientists for around 2000 years until Sir Robert Boyle (1627–1691), an English scientist, used them again. To Boyle, elements were "primitive and simple, and perhaps unmingled bodies"—atoms. But Aristotle's elements did not fade from view that quickly. While some chemists relied on atoms for some of their work in the next 120 years, others still used Aristotle's four elements.

Dalton's theory makes the difference

In 1803, John Dalton, a British chemist, published his atomic theory. Dalton thought of the smallest particles of elements as simple little balls. He drew circles to represent them, and shaded the circles in different ways to show different elements (figure 17·14).

Dalton knew that elements have different properties. And according to his theory the simplest particles of an element also have different properties than those of any other element. These particles differ in size and weight. But all particles of one element are alike.



Dalton called his particles "atoms" because he thought they were similar to the ones described by Democritus.

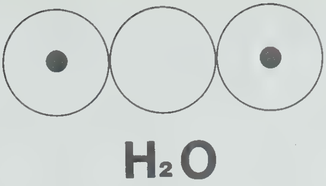
The scientific discoveries of the 1700's made the value of Dalton's theory easy to see. Modern atomic theory grew out of the research of the last 150 years. It changes continually as more experimental evidence is gathered. But it still has some points in common with Dalton's theory.

According to both theories, atoms join together to form the molecules of more complex substances, called *compounds*. For instance, atoms of hydrogen and oxygen combine to form molecules of water. The molecule is the smallest particle of a compound such as water. A water molecule cannot be broken down into the atoms of hydrogen and oxygen without being destroyed. And the properties of the water molecule are different from the properties of the elements that combined to form it (Table 1).

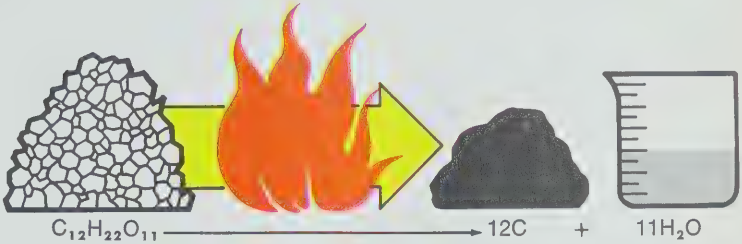
Table 1

Substance	Formula	Appearance	Density grams per 1000 cc	Melting point in °C	Boiling point in °C
Hydrogen	H	colorless gas	0.0899	−259.14	−252.8
Oxygen	O	colorless gas	1.429	−218.4	−183.0
Water	H_2O	colorless liquid	1000.0	0	+100.0

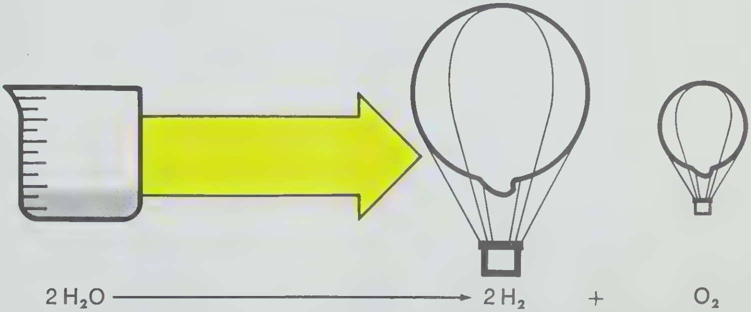
A molecule does not always consist of one atom of each of the elements that have combined to form it. Water, for instance, has two atoms of hydrogen and one atom of oxygen in each molecule. But the atoms that make up a molecule are always present in fixed whole numbers. A molecule can never contain part of an atom because, according to atomic theory, an atom is the simplest part of an element that retains the properties of that element.



17·15 Dalton combined the circles for hydrogen and oxygen to show a water molecule. He should have put a circle for oxygen between two circles for hydrogen. Modern chemists show molecules by joining the letter symbols of the elements.



17·16 When sugar burns, the sucrose breaks down to give 12 atoms of carbon and 11 molecules of water.



17·17 When water decomposes, two molecules of water break down to give two molecules of hydrogen and one molecule of oxygen.

Modern chemists use letters instead of shaded circles to represent each of the elements. H stands for hydrogen; O for oxygen. Fe is iron, from the Latin word *ferrum* which means iron. The symbols of the elements are on pages 458 and 459.

Chemical words, or *formulas*, are used to describe molecules (figure 17·15). The numeral to the right of and slightly below the letter symbol tells how many atoms of that element are in the molecule. Water contains 2 atoms of hydrogen and 1 of oxygen. The table-sugar molecule, $C_{12}H_{22}O_{11}$, contains 12 atoms of carbon, 22 of hydrogen, and 11 of oxygen.

Sentences called *equations* are used to describe chemical reactions (figure 17·16). Notice that there are always the same number of atoms of each element on both sides of the arrow. And there are never just parts of atoms in an equation.

For instance, you cannot break down one molecule of water to get two atoms of hydrogen and one atom of oxygen (figure 17·17). Hydrogen and oxygen are two of the gaseous elements that do not normally exist as single atoms. The atoms of these elements immediately combine to form molecules. Hydrogen and oxygen both exist as two-atom molecules.

Some other gaseous elements that exist as two-atom molecules are nitrogen (N_2), chlorine (Cl_2), and fluorine (F_2).

Table 2 lists the formulas for each of the compounds mentioned in this chapter. And Table 3 gives the equation for each of the reactions you have observed. If you can tell what each of the letters and numerals means, you are beginning to learn the language of chemistry.

Table 2

Formulas of some chemicals in chapters 16 and 17

Substance	Formula	Substance	Formula
Acetic acid (vinegar)	$HC_2H_3O_2$	Manganese dioxide	MnO_2
Aluminum oxide	Al_2O_3	Silver chloride	$AgCl$
Ammonia, household	NH_4OH	Silver nitrate	$AgNO_3$
Calcium carbonate (limestone)	$CaCO_3$	Sodium bicarbonate	$NaHCO_3$
Calcium oxide	CaO	Sodium chloride (table salt)	$NaCl$
Carbon dioxide	CO_2	Sodium hydroxide	$NaOH$
Carbon monoxide	CO	Sodium nitrate	$NaNO_3$
Hydrochloric acid	HCl	Sucrose (table sugar)	$C_{12}H_{22}O_{11}$
Hydrogen peroxide	H_2O_2	Sulfuric acid	H_2SO_4
Iron oxide	Fe_2O_3	Water	H_2O
Iron sulfate	$Fe_3(SO_4)_3$	Zinc chloride	$ZnCl_2$

Table 3

Chemical reactions in chapter 17

Chemical reaction	Equation
Heating sugar	$C_{12}H_{22}O_{11} + \text{heat} \longrightarrow 12C + 11H_2O$
Heating limestone	$CaCO_3 + \text{heat} \longrightarrow CaO + CO_2$
Iron with sulfuric acid	$2Fe + 3H_2SO_4 \longrightarrow Fe_2(SO_4)_3 + 3H_2$
Zinc with hydrochloric acid	$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$
Aluminum with sodium hydroxide	$2Al + 6NaOH \longrightarrow 2Na_3AlO_3 + 3H_2$
Aluminum with oxygen (air)	$4Al + 3O_2 \longrightarrow 2Al_2O_3$
Iron with oxygen	$4Fe + 3O_2 \longrightarrow 2Fe_2O_3$
White phosphorus with oxygen	$P_4 + 5O_2 \longrightarrow P_4O_{10}$
Ammonia with vinegar	$NH_4OH + HC_2H_3O_2 \longrightarrow NH_4C_2H_3O_2 + H_2O$
Sodium bicarbonate with vinegar	$NaHCO_3 + HC_2H_3O_2 \longrightarrow NaC_2H_3O_2 + CO_2 + H_2O$
Hydrogen with oxygen (Platinum catalyst)	$2H_2 + O_2 + \underset{\text{catalyst}}{Pt} \longrightarrow 2H_2O + \underset{\text{catalyst}}{Pt}$
Decomposition of hydrogen peroxide	$2H_2O_2 + \underset{\text{catalyst}}{MnO_2} \longrightarrow 2H_2O + O_2 + \underset{\text{catalyst}}{MnO_2}$
Silver nitrate with sodium chloride	$AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$

The development of modern atomic theory followed the discovery of a way to classify the elements

The Story of the Atom Part 2

The periodic table

In the early 1800's several chemists noticed that certain elements have similar chemical properties. For instance, nearly every reaction that takes place between oxygen and a metal also takes place between that metal and sulfur. Although oxygen is a gas and sulfur a solid, they react similarly. They belong to one group of elements.

Chemists noticed that other elements could be placed in groups according to the types of reactions in which they took part. So they placed all the known elements in groups on this basis. As they discovered each new element, chemists found that it too fit into one of the groups.

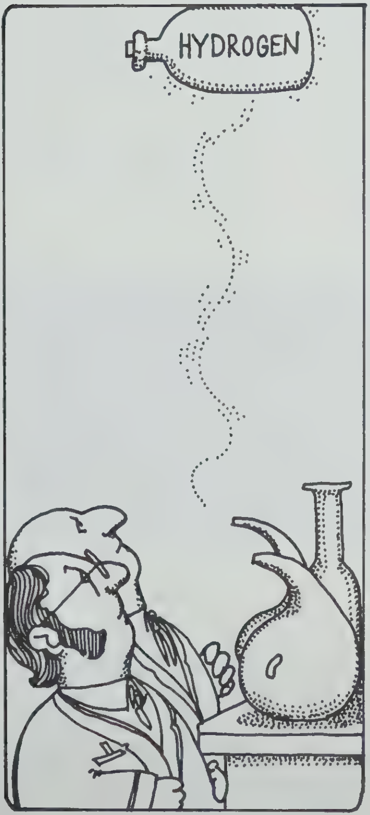
While they were studying the reactions in which the elements take part, some chemists found a means of comparing the weight of atoms of the elements. They had a roundabout way of doing it since single atoms couldn't be weighed.

For example, they had noticed that 1 gram of hydrogen always combines with 35.5 grams of chlorine to form the compound hydrogen chloride (HCl). From other evidence the chemists knew that each molecule of hydrogen chloride contains one atom of hydrogen and one atom of chlorine. From still other observations, they knew that hydrogen was the lightest element. By putting all these pieces of evidence together, they estimated how much heavier than a hydrogen atom each atom of chlorine was.

To set some sort of means by which to compare the weights of atoms, they assigned the number 1 as the weight of a hydrogen atom. In relation to that an atom of chlorine must have a weight of 35.5.

By combining and comparing other elements in this way, chemists continued to find their weights. Then Jöns Jakob Berzelius (bər zē′lē əs), a Swedish chemist, listed the weights of all the elements then known. He called these weights the relative *atomic weights* of the elements.

Up to this point, there were two ways to classify elements—by the reactions in which they took part and by their atomic weights. Nobody thought of looking at both classifications at the same time until 1869 when a Russian chemist, Dmitri Mendeleev (men′də-lā′yəf), provided the way. He arranged the elements in rows across



17·18 "That one must be the lightest element!"

the paper according to the order of their atomic weights. But he stopped each row so that elements with similar chemical properties were listed one below the other. His arrangement is called the *periodic table of the elements* (figure 17·19).

The periodic table is used by chemists because it contains a great deal of information in a convenient form. On it a chemist can find the atomic weight of an element, the reacting group to which it belongs, and other information, some of which is described below.

The divisible atom

Research on the elements continued. One of the interesting discoveries was that the atom, for which the word meaning "indivisible" was used, could be divided.

17·19

Transition Elements

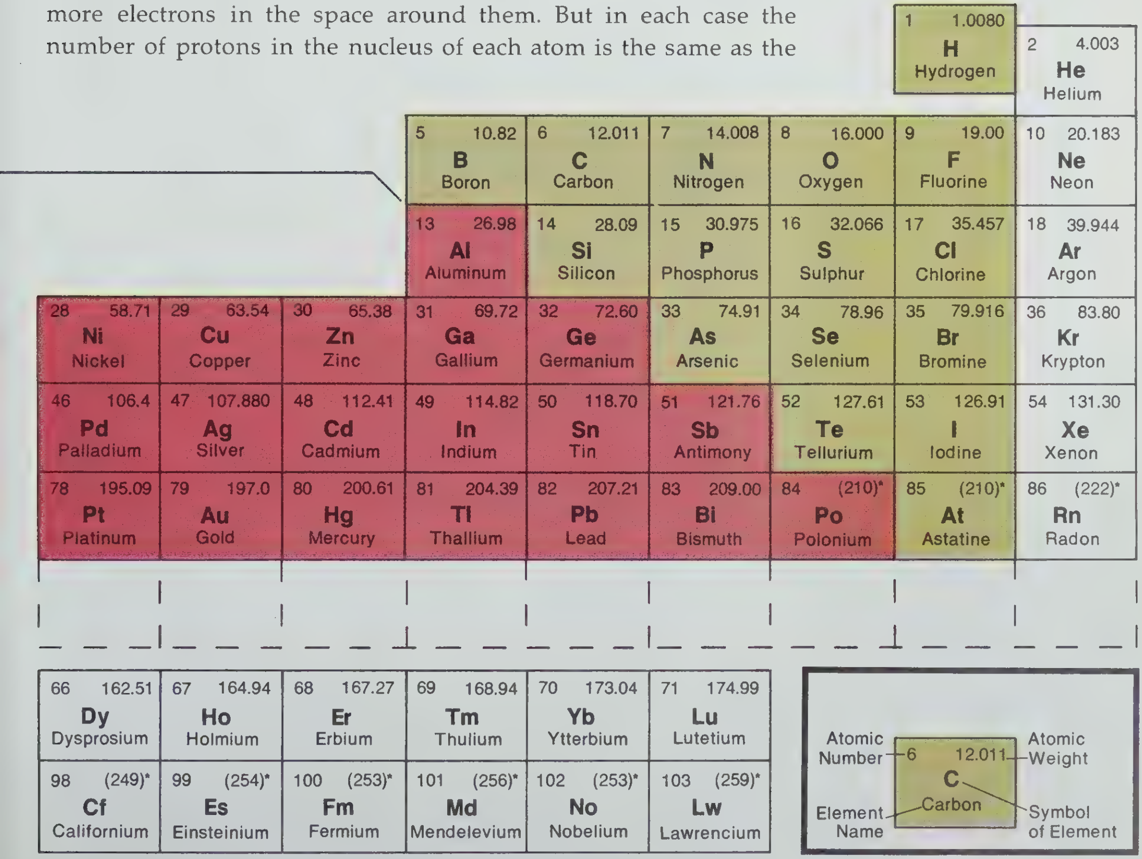
1 1.0080 **H** Hydrogen								
3 6.940 **Li** Lithium	4 9.013 **Be** Beryllium							
11 22.991 **Na** Sodium	12 24.32 **Mg** Magnesium							
19 39.100 **K** Potassium	20 40.08 **Ca** Calcium	21 44.96 **Sc** Scandium	22 47.90 **Ti** Titanium	23 50.95 **V** Vanadium	24 52.01 **Cr** Chromium	25 54.94 **Mn** Manganese	26 55.85 **Fe** Iron	27 58.94 **Co** Cobalt
37 85.48 **Rb** Rubidium	38 87.63 **Sr** Strontium	39 88.92 **Y** Yttrium	40 91.22 **Zr** Zirconium	41 92.91 **Nb** Niobium	42 95.95 **Mo** Molybdenum	43 (99)* **Tc** Technetium	44 101.1 **Ru** Ruthenium	45 102.91 **Rh** Rhodium
55 132.91 **Cs** Cesium	56 137.36 **Ba** Barium	57 138.92 **La** Lanthanum ■	72 178.50 **Hf** Hafnium	73 180.95 **Ta** Tantalum	74 183.86 **W** Tungsten	75 186.22 **Re** Rhenium	76 190.2 **Os** Osmium	77 192.2 **Ir** Iridium
87 (223)* **Fr** Francium	88 (226)* **Ra** Radium	89 (227)* **Ac** Actinium ■■	104 (260)* **?** Unnamed					

■ Lanthanide Series	58 140.13 **Ce** Cerium	59 140.92 **Pr** Praseodymium	60 144.27 **Nd** Neodymium	61 (145)* **Pm** Promethium	62 150.35 **Sm** Samarium	63 152.0 **Eu** Europium	64 157.26 **Gd** Gadolinium	65 158.93 **Tb** Terbium
■■ Actinide Series	90 232.05 **Th** Thorium	91 (231)* **Pa** Proactinium	92 238.07 **U** Uranium	93 (237)* **Np** Neptunium	94 (242)* **Pu** Plutonium	95 (243)* **Am** Americum	96 (248)* **Cm** Curium	97 (247)* **Bk** Berkelium

*Atomic weights appearing in parentheses are those of the most stable known form.

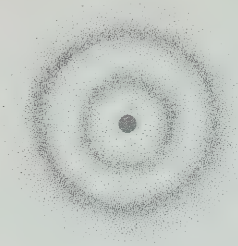
The atom was found to consist mainly of empty space, but it has a very tiny, very heavy core. This core, called the *nucleus*, contains all the positive charge of the atom. There are negatively charged particles in the space around the nucleus. There are enough of these particles, called *electrons*, to keep the atom electrically neutral. For instance, the hydrogen atom (the smallest atom) has one positive charge in its nucleus. Such a positive charge is called a *proton*. In the space around it, there is one negative charge, the electron.

Atoms of other elements have more protons in their nuclei, and more electrons in the space around them. But in each case the number of protons in the nucleus of each atom is the same as the

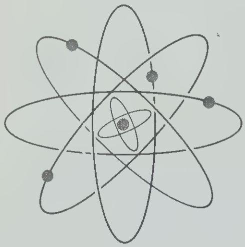


							1 1.0080 **H** Hydrogen	2 4.003 **He** Helium
			5 10.82 **B** Boron	6 12.011 **C** Carbon	7 14.008 **N** Nitrogen	8 16.000 **O** Oxygen	9 19.00 **F** Fluorine	10 20.183 **Ne** Neon
			13 26.98 **Al** Aluminum	14 28.09 **Si** Silicon	15 30.975 **P** Phosphorus	16 32.066 **S** Sulphur	17 35.457 **Cl** Chlorine	18 39.944 **Ar** Argon
28 58.71 **Ni** Nickel	29 63.54 **Cu** Copper	30 65.38 **Zn** Zinc	31 69.72 **Ga** Gallium	32 72.60 **Ge** Germanium	33 74.91 **As** Arsenic	34 78.96 **Se** Selenium	35 79.916 **Br** Bromine	36 83.80 **Kr** Krypton
46 106.4 **Pd** Palladium	47 107.880 **Ag** Silver	48 112.41 **Cd** Cadmium	49 114.82 **In** Indium	50 118.70 **Sn** Tin	51 121.76 **Sb** Antimony	52 127.61 **Te** Tellurium	53 126.91 **I** Iodine	54 131.30 **Xe** Xenon
78 195.09 **Pt** Platinum	79 197.0 **Au** Gold	80 200.61 **Hg** Mercury	81 204.39 **Tl** Thallium	82 207.21 **Pb** Lead	83 209.00 **Bi** Bismuth	84 (210)* **Po** Polonium	85 (210)* **At** Astatine	86 (222)* **Rn** Radon

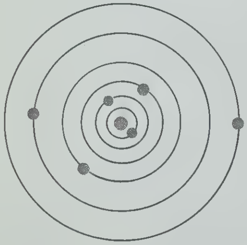
66 162.51 **Dy** Dysprosium	67 164.94 **Ho** Holmium	68 167.27 **Er** Erbium	69 168.94 **Tm** Thulium	70 173.04 **Yb** Ytterbium	71 174.99 **Lu** Lutetium
98 (249)* **Cf** Californium	99 (254)* **Es** Einsteinium	100 (253)* **Fm** Fermium	101 (256)* **Md** Mendelevium	102 (253)* **No** Nobelium	103 (259)* **Lw** Lawrencium



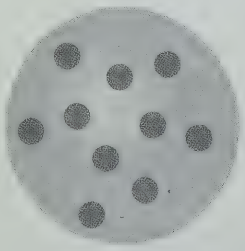
Quantum model



Classical model



Bohr model



Plum-pudding model

17·20

number of electrons in the space around it. And the number assigned to each element on the periodic table turned out to be the same as the number of protons in the nucleus of an atom of that element. That number is called the *atomic number* of the element. Each element has a different atomic number. This indicates that an atom of one element has a different number of protons in its nucleus than an atom of any other element.

When you look at the atomic number and the atomic weight assigned to each element on the periodic table, you'll notice something interesting. For example, the atomic weight of the hydrogen atom is almost the same as its atomic number—1. Nearly all of the weight of an atom has been found to be in its nucleus. So the proton can be assumed to have an atomic weight of 1.

However, there is more to the story of what we now know to be a divisible atom. Researchers had evidence that the helium atom nucleus contains 2 protons. So we would assume that helium has an atomic weight of 2. But according to the periodic table, helium has an atomic weight of 4. The rest of the weight was found to be due to the presence of another kind of particle in the helium nucleus. The helium atom has two of them. Each of these particles has about the same relative weight as a proton, but no electric charge. These neutral particles are called *neutrons.*

We can picture a divisible atom that consists of a nucleus containing protons and neutrons with electrons in the space around the nucleus. Figure 17·20 shows some ways we can picture the divisible atom.

Using physical properties, chemical properties, and nuclear chemistry to solve crime

"Who-dun-it?"

A man is found lying unconscious in the street at daybreak. He seems to be the victim of a hit-and-run accident. No witnesses are available. The police were notified by an anonymous phone call. The investigating officer notices a smear of paint on the man's coat. He carefully places a few flakes of it in an envelope and sends it to the crime laboratory.

The crime laboratory has a staff of *forensic* scientists, people trained to use science to solve problems of civil or criminal law. One uses a microscope to study the layers and colors of the paint. The scientist may test each layer with solvents to find out whether it is oil base or plastic.

If the sample were larger, he or she would use an instrument called an emission spectograph to find which chemical elements are present. This instrument heats a paint flake until it vaporizes and begins to glow. Atoms of each element in the sample give off light having specific wavelengths which the instrument sorts out into a series of lines (line spectrum) shown on a dark background. This indicates what elements are present. Titanium, magnesium, and aluminum are common in auto paints.

17·21 Scientist testing for the presence of a drug.

The policeman gave the crime lab a very small paint sample. So it is important to get a chemical analysis without destroying it. One very sensitive way to do this is called neutron activation analysis. The sample is placed in a nuclear reactor and bombarded with neutrons, causing some of its atomic nuclei to become temporarily radioactive. Then the elements in the sample and their concentrations are identified from the kind of radioactivity emitted, its strength, and its rate of decay.

Neutron activation may also be applied to samples such as glass, soil, metals, gunpowder residues, or hair. One interesting use is in cases of poisoning with metallic poisons, such as arsenic and lead, which concentrate in hair.

The hospital has reported that the victim may have been drugged or poisoned before he was hit by the car. The analysis of his hair shows no arsenic, but the crime laboratory staff will do many other tests before they discard the doctor's suspicion. In general, much more work is needed before neutron activation becomes a reliable routine procedure, but it shows promise.

The forensic scientists who analyzed the paint have used their findings and information supplied by auto manufacturers to find the color, make, and year of car that the paint came from. They give this information to the police, who find a suspicious car fitting the description. The car has a broken headlight, dents, paint scrapes, and some stains that look like blood. Samples of glass from the headlights, paint, and the stains are sent to the crime laboratory. These samples will be evidence that the car was or was not at the scene of the alleged crime.

Chemical analysis of the glass tells the forensic scientists little, because the chemical elements contained in most glass are similar. But some physical properties can differ. One of the forensic scientists may try to match the density of a piece of glass found in the street under the victim with that of the broken headlight. He or she would also probably determine its index of refraction by measuring how much light rays are bent as they pass through it.

The laboratory reports that the glass and paint seem to have come from the suspected car. But the police want more evidence.

Is it blood?

The detective in charge of the case asks a forensic scientist to identify the stains found on the suspicious car. Blood stains are not always red or brown. They may appear tan, green, or even gray, depending on their age or their surroundings. To find out if it could be blood, the scientist performs the benzidine test on a sample of the stain.

He or she mixes a colorless chemical called benzidine acetate with hydrogen peroxide and a bit of the sample. A bright blue color forms immediately, meaning that blood is probably present. The color forms when benzidine acetate reacts with the oxygen produced by the decomposition of hydrogen peroxide.

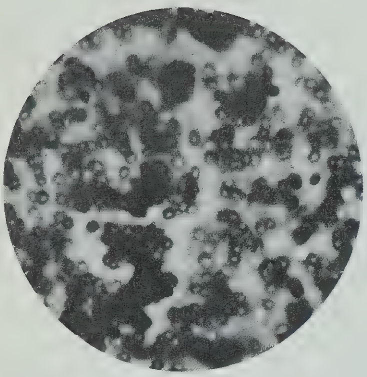
This decomposition takes place slowly without blood. But if blood is present, it happens almost instantly. The enzyme peroxidase in the blood catalyzes the decomposition of hydrogen peroxide. The benzidine test is very sensitive and detects even very old stains. However, other substances, including rust, also give a positive test so these possibilities must be eliminated.

Is it human blood?

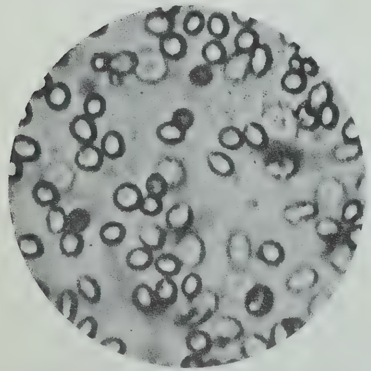
If the scientist is sure the stain is blood, he or she must find whether it is human or animal. The blood could be that of a dog or cat hit by the car. The scientist uses a test developed around 1900 by a German chemist, Paul Uhlenhuth (ü′lən hüt), to find out if the blood is human.

Blood contains a variety of proteins which differ slightly from one species of animal to another. Some of these are in the blood serum, the watery portion remaining when blood cells are removed. Uhlenhuth found that when he injected serum obtained from chicken blood into a rabbit, proteins called antibodies built up in the rabbit's blood serum to destroy the proteins from the chicken. Then, when a sample of the rabbit's serum was placed in a test tube with serum from a chicken, a flaky white precipitate formed. The test is called the precipitin test.

Antibodies can be produced for other species in the same way and used to distinguish among them. To find out if it is human



17·22a Positive agglutination test. The blood cells have clumped.



17·22b Negative agglutination test.

blood, the scientist dissolves the suspicious blood stain in a weak solution of salt and water. He or she then mixes it with a series of rabbit serums containing known antibodies, such as dog, horse, chicken, and human.

If the sample is human blood, it will turn white with human antibodies, but not with the others. Only such closely related species as donkeys and horses or apes and humans cannot be distinguished because their proteins are too much alike.

Is it the victim's blood?

The stain proved to be human blood. But that wasn't enough evidence to take the case into court. Human blood can be divided into four major groups; A, B, O, and AB. The victim's blood group is B. This classification is based on proteins in blood cells, called agglutinogens. These cause blood cells to clump together (agglutinate) when certain groups are mixed. The scientist compares some of the sample scraped off the car with dilutions of known groups and finds that it too is group B. This is an important bit of evidence that links the car to the alleged crime.

Is the suspicious car stolen?

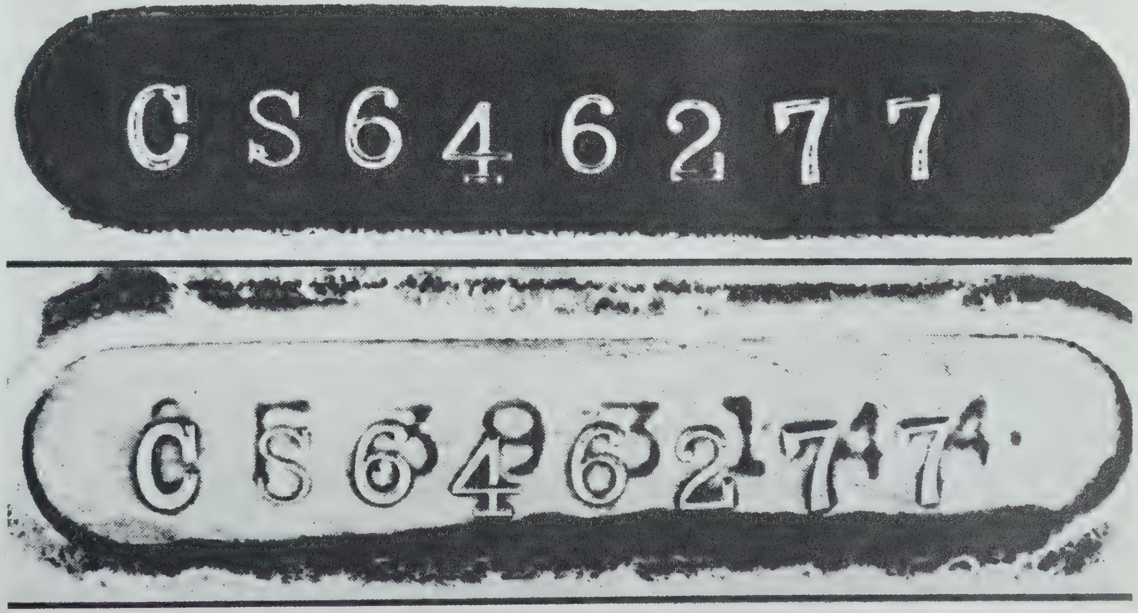
In his semi-conscious state, the victim has been mumbling something about a stolen-car ring. If the suspicious car was stolen, its engine might have a fake serial number. Thieves sometimes file down the original number and stamp a fake one over the same place to make the car hard to trace. However, a forensic scientist may still be able to read the original number. The original stamping compressed the metal crystal structure to a level below the filed level.

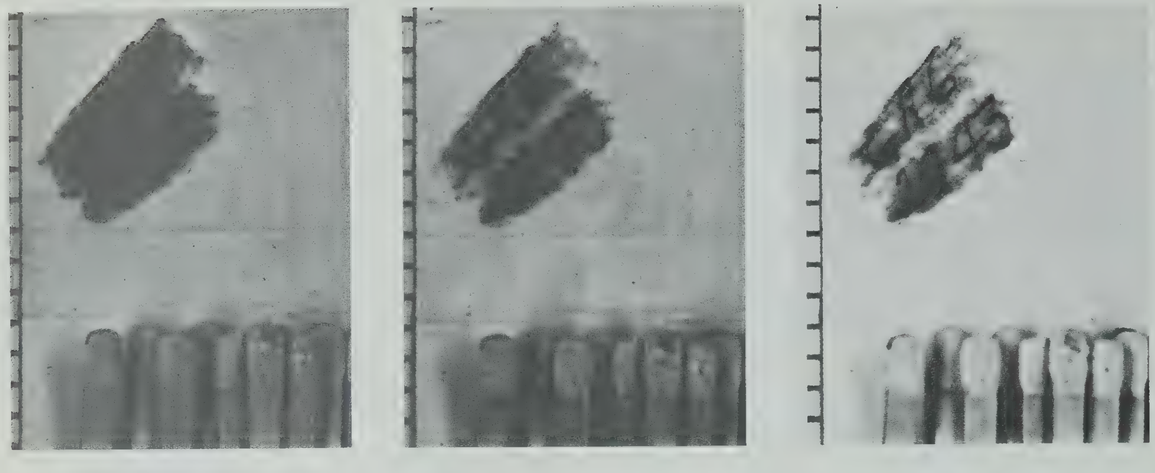
To reveal the numbers, the scientist files the surface smooth and treats it with a mixture of hydrochloric acid (HCl) and copper chloride ($CuCl_2$). This slowly dissolves the entire surface. But it works more slowly on the small compressed crystals than on the larger crystals of the surrounding areas. Both old and new numbers appear to rise up. They remain visible long enough to be photographed and then they too dissolve. Original serial numbers on stolen guns can be seen this way too.

The police are having a hard time identifying the victim. His fingerprints are not on file with the FBI. And the identification card in his wallet has been tampered with. The address listed on it is that of an empty lot.

Ink eradicator seems to have been used to remove one address before replacing it with another. But ink eradicators only destroy that part of the ink molecule which absorbs visible light. The remainder of the molecule may be visible in an infrared photograph.

17•23 Hidden serial numbers can be brought out.





17·24 Scratched out numbers on the matchbook can be read on photographs taken in infrared light.

As soon as the forensic scientists find the original address on the card, they notify the police.

The police find an empty apartment. But there is a piece of charred paper in the sink. They also find a matchbook with something crossed out on its cover in one corner of the bedroom. A forensic scientist photographs the paper and the matchbook in infrared light and the hidden information shows up in the photographs.

The police put together all the information given them by the crime laboratory. With that and the story told by the victim who is finally well enough to talk, they are able to make an arrest.

When the case comes to court, the prosecuting attorney will claim that this was no mere hit-and-run accident. It was attempted murder. The victim had innocently bought a stolen car and was being blackmailed by the seller. When he threatened to notify the police, the seller drugged him, let him out in the middle of the street, and ran him down with the car.

The tests done by the forensic scientists will be used as evidence in the trial. Tests in forensic science require great accuracy because reputations and even lives of persons accused of crimes are often at stake. The forensic scientists must testify in court. They must be able to explain the results of their complicated tests in simple clear terms to judges and juries who have no scientific training.

Chapter 18: Metals

18

There has not yet been agreement as to how long there have been human beings on our planet. Scientists have traced the history of humanlike animals backward through over 1$\frac{1}{2}$ million years.

One way they have classified the remains they found is through the tools located nearby. The earliest tools were fashioned out of stone. Those who made and used them are said to have lived in the Stone Age.

Around 3000 B.C. people living in the area we call the Middle East began to make their tools of bronze. Bronze is a mixture or *alloy* of copper and tin.

In the Middle East the Bronze Age lasted until about 1100 B.C. Around that time people started to make their tools out of iron. The Iron Age and the use of iron have continued to this time. But today, people also use many other metals.

About 80 of the chemical elements are metals. Of these, some 15 are used regularly in technology and industry. Another 15 are used now and then. And the rest are of interest mainly to the chemist. In this chapter, we will deal only with the most common metals.

The Marvels of Metals

Metals are more alike in their physical properties than in their chemical properties. When polished, they are shiny substances that reflect light much as mirrors do.

With the exception of the liquid metal, mercury, all metals are flexible solids. They can be hammered into sheets and bars, drawn into wire, and "worked" in many ways. Yet, they remain strong. The strength and flexibility of metals are important reasons for their use in construction, transportation, and machine manufacture.

All metals are conductors of heat and electricity. Some conduct electricity well enough to be used in the electrical industry. Others do not conduct as well, but none are insulators.

Metals, thus, are extremely useful. But there are problems involved in their use. These include cost, chemical reactivity, and high density (mass per unit volume). Most of the common metals readily react with a large variety of chemicals. Because these include air—especially moist air—most metallic objects are slowly eaten away.

A few metals such as gold, platinum, and silver are less reactive. But these are also expensive and among the most dense metals. They increase the cost and the weight of any object made of them. Therefore, the cheaper, less dense, and more reactive metals are used more often in technology and industry.

BANKERS TRUST COMPANY
EASTERN

Salvo
PLASTIC CUPS

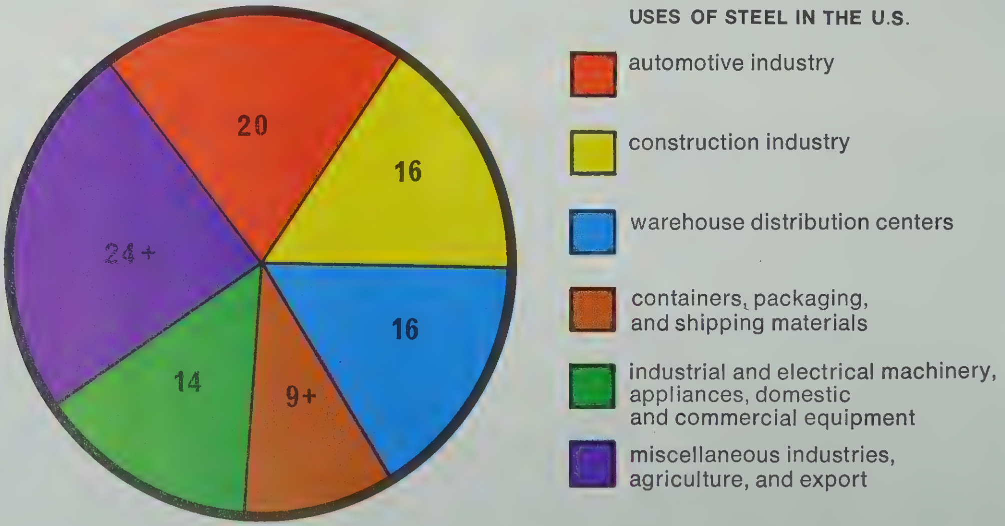
IRON

18·7 Pure iron

Iron is the most used metal. Nearly 600 million tons of iron are produced throughout the world every year. It is the least costly and most versatile metallic building material. There are few places where metals other than iron must be used.

The purest form of iron in common use is wrought iron. This iron is made by the refining of iron ore. Wrought iron contains carbon and small amounts of other elements as impurities. Its properties are such that its range of use is very limited. Most iron is changed into steel in a second refining step in which *some* of the carbon is removed. Steel is an *alloy*—a mixture of iron with other elements.

The properties of iron and its alloy, steel, change greatly with carbon content. Pure iron, which has been made for laboratory use, is silvery white, fairly soft, and magnetic. Wrought iron, containing a little carbon, is much harder, but it can still be worked and hammered easily. Steel varies in its properties from "soft steel" with little carbon content, to tougher and stronger steel with greater amounts of carbon.



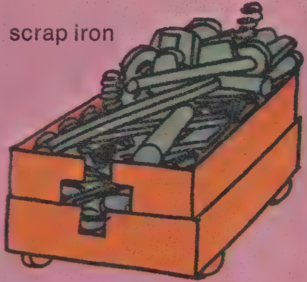
18·8

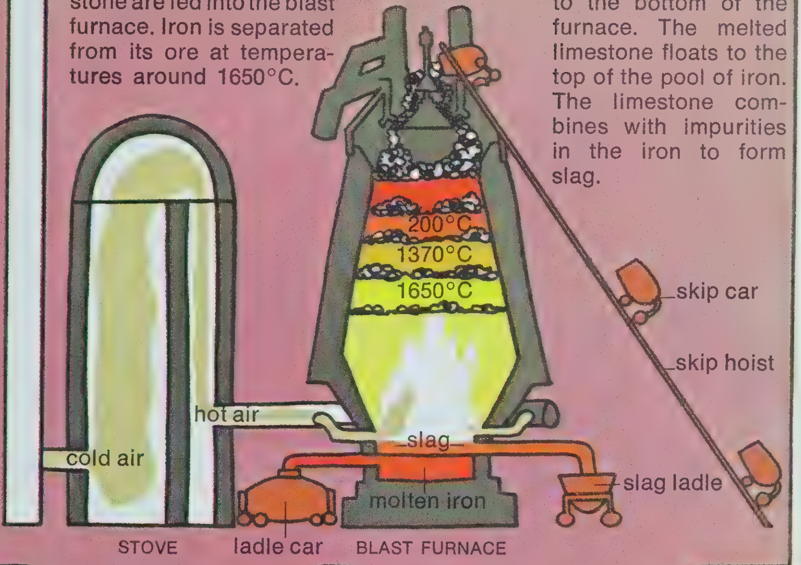
Steel is made from iron ore and from steel scrap. The iron ore is reduced to iron in the blast furnace.

Steel scrap is recycled in the basic oxygen, open hearth, and electric furnaces.

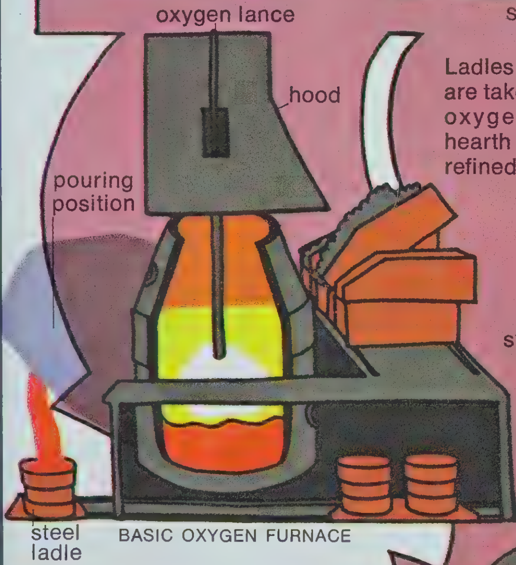
Iron ore, coke, and limestone are fed into the blast furnace. Iron is separated from its ore at temperatures around 1650°C.

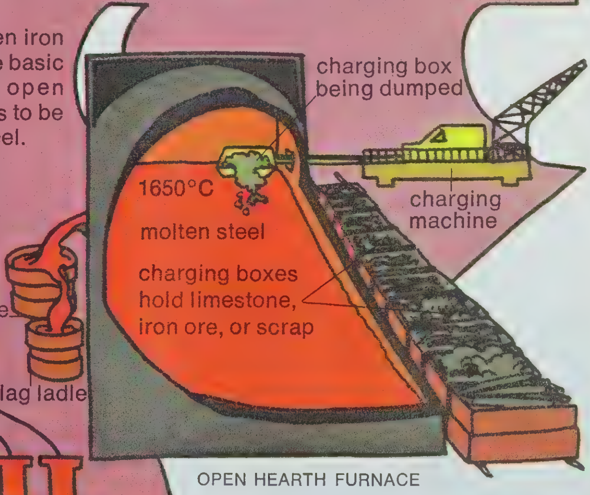
The molten iron falls to the bottom of the furnace. The melted limestone floats to the top of the pool of iron. The limestone combines with impurities in the iron to form slag.



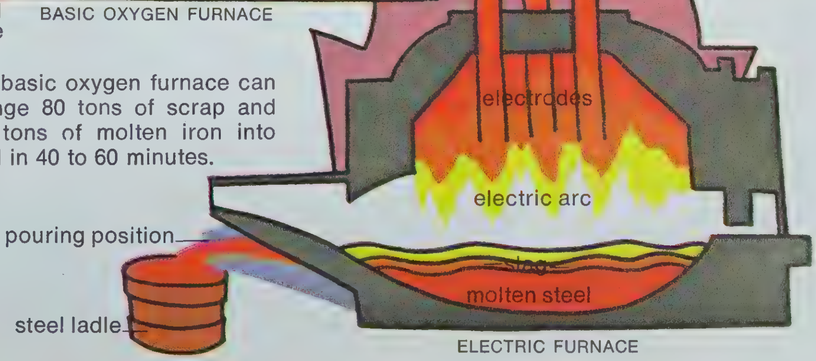


Ladles of molten iron are taken to the basic oxygen and open hearth furnaces to be refined into steel.




charging box being dumped
1650°C
charging machine
molten steel
charging boxes hold limestone, iron ore, or scrap
steel ladle
slag ladle
OPEN HEARTH FURNACE

The basic oxygen furnace can change 80 tons of scrap and 200 tons of molten iron into steel in 40 to 60 minutes.



Most of the steel made in the United States is made in open hearth furnaces.

The electric furnace is used to make alloy steels out of scrap.

Molten steel from any of these furnaces is further processed to provide the countless steel products we see every day.

OTHER COMMON METALS

Aluminum is the metal next in importance to iron. Almost 11 million tons of aluminum are produced throughout the world each year. An important and useful property of aluminum is its low density, about one-third that of iron. In addition, aluminum is a good conductor of electricity, making it suitable for electricity transmission lines.

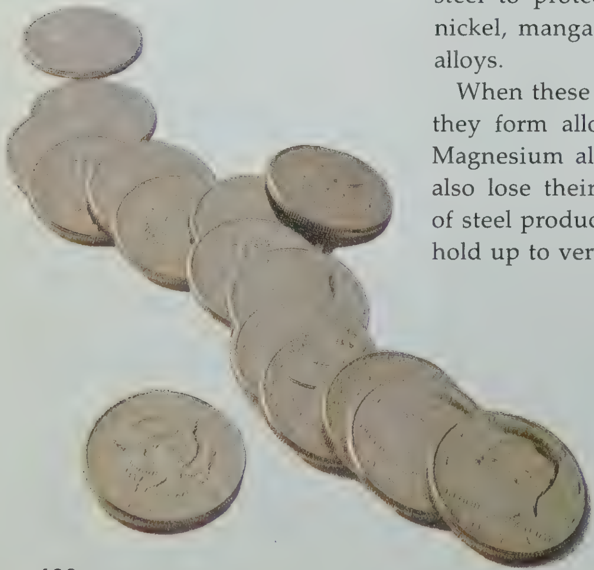
Copper is the third most important metal, in terms of tons produced. World production totals about 7.1 million tons a year. Small amounts of copper are used to make alloys like brass and bronze. Most of the copper produced is used in electrical equipment because it is the best conductor among the common metals.

Only two other metals are used in any significant amounts. The yearly world production of zinc is just over 5.5 million tons. Zinc is used mainly in the protection of steel against rusting. Yearly world production of lead is about 4 million tons. It is used chiefly in the manufacture of automobile batteries.

The world production of the other common metals cannot be measured in millions of tons. However, those metals are easily available and widely used. Tin, chromium, and nickel are plated on steel to protect it against rusting. Magnesium, cobalt, tungsten, nickel, manganese, titanium, and chromium are used to produce alloys.

When these metals are added to steel or aluminum or each other, they form alloys, each of which has its own special properties. Magnesium alloys of aluminum have very low density, but they also lose their strength at fairly low temperatures. Cobalt alloys of steel produce the strongest permanent magnets. Tungsten alloys hold up to very abrasive conditions at high temperatures.

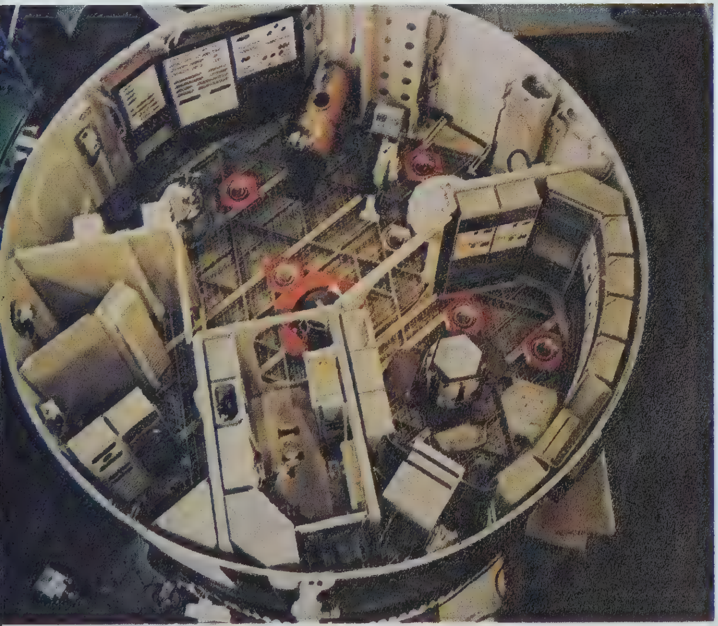
18·10 The Kennedy half dollars have a copper core covered with a 75-percent copper and 25-percent nickel alloy.



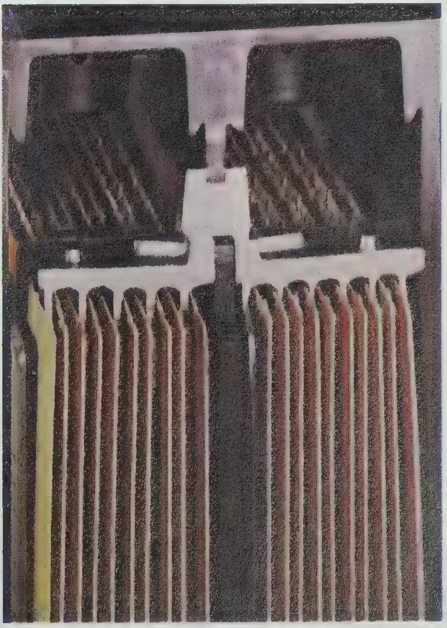
18·11 Sample aluminum cans for soft drinks.

18·12 Cobalt compounds color the blue pieces of pottery. Nickel compounds color the black pieces.

18·13 Cross section of the almost totally metal spacelab.



18·14 Lead storage battery



The common metals are used in many ways. Each metal is chosen for a specific use according to its physical and chemical properties. Melting point, boiling point, density, and hardness are important. So is the likelihood that the metal will or will not take part in a chemical reaction.

This likelihood varies greatly for the common metals. Gold is not likely to react. It is found in nature as a pure metal. Iron is not. Unless iron is protected, it will quickly combine with the oxygen in air. Iron is found in nature mainly as oxides (iron-oxygen compounds).

You do not have to look far to see differences in the reactivity of common metals. Perhaps there are copper pots in your kitchen, or aluminum window frames in your home. Does copper "rust" like iron? Have you ever seen aluminum "rust"? What about any other metals?

Most metals react naturally with the oxygen in the air. Some react very quickly and at low temperatures. Others react only at high temperatures. Only gold, silver, and platinum do not react at all, or react so slowly it is hard to detect the reaction.

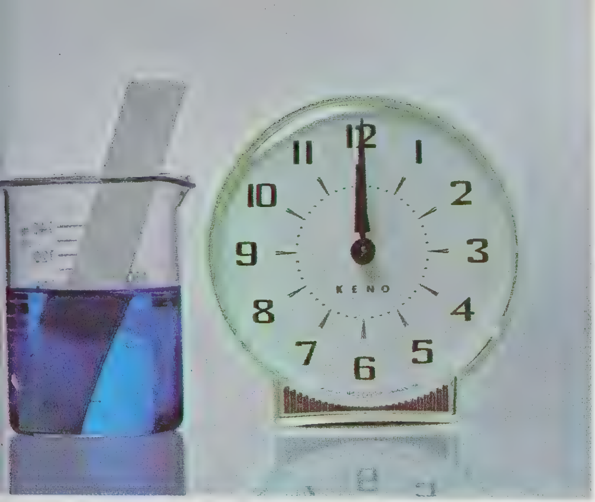
When a metal reacts with the oxygen in the air, the atoms of the metal combine with atoms of oxygen. The *combination* reaction can be shown:

metal + oxygen → metal oxide

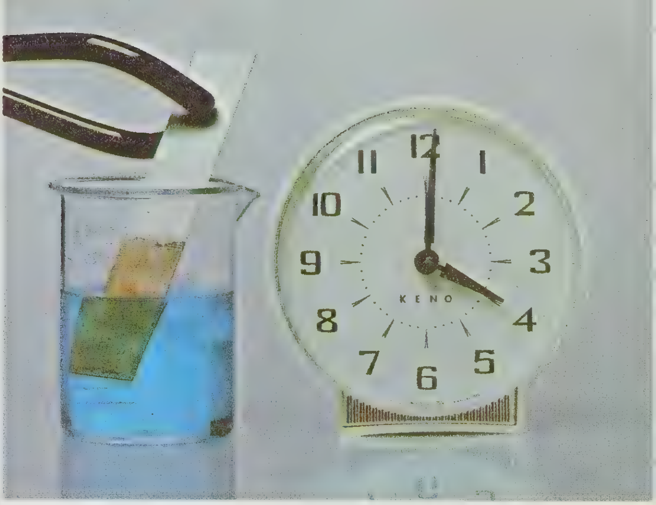
Similar combination reactions take place when metals are exposed to the gaseous element, chlorine. These reactions can be shown in a similar way:

metal + chlorine → metal chloride

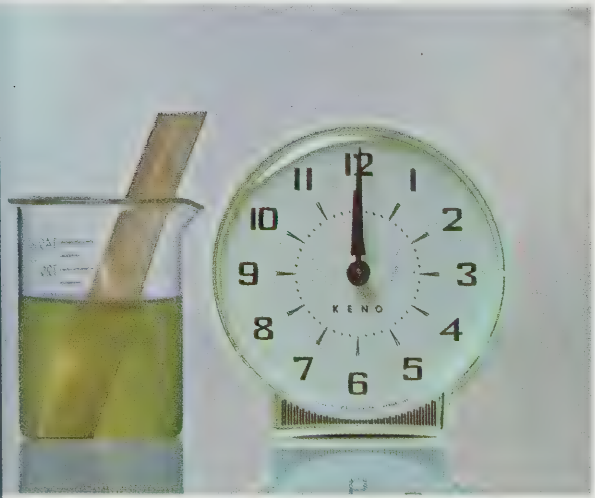
18·15 Copper roof of the Chicago Water Tower. Its blue-green *patina* is due to the formation of a protective surface film of a copper compound.



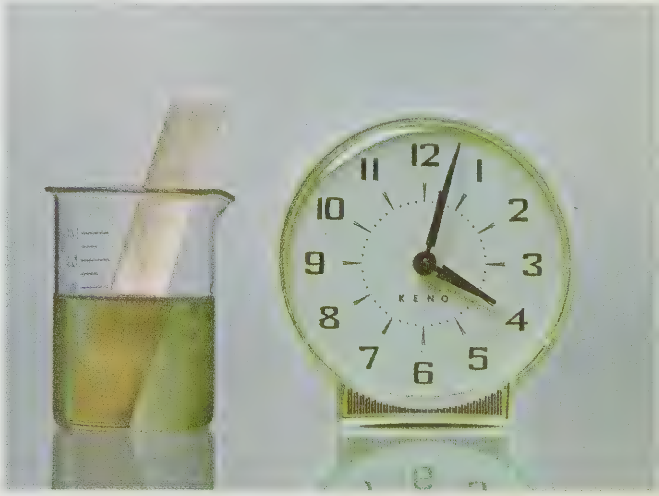
18•16a Iron strip in a solution of a copper compound.



18•16b Four hours later, a copper-colored layer has formed on the iron strip.



18•16c Copper strip in a solution of an iron compound.



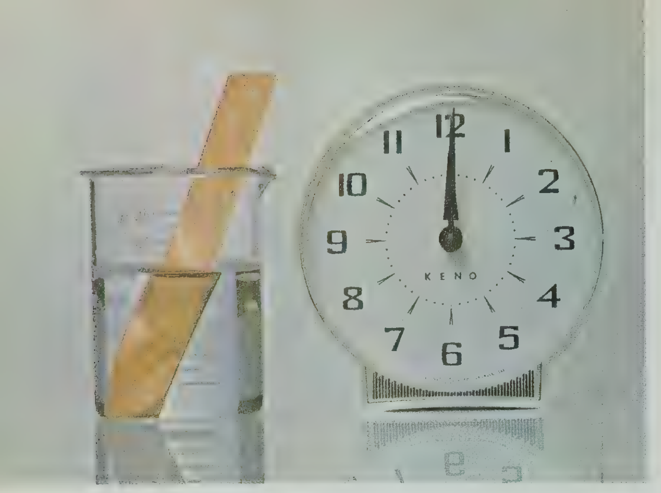
18•16d Four hours later, no change is visible.

Metal-chlorine reactions occur much faster than metal-oxygen reactions. But they do not take place at the same speed for every metal. Iron and zinc react very rapidly with both oxygen and chlorine. Metals like tin and lead that seldom react with the oxygen in the air react slowly with chlorine. And metals like silver and gold that do not react with oxygen react very slowly with chlorine.

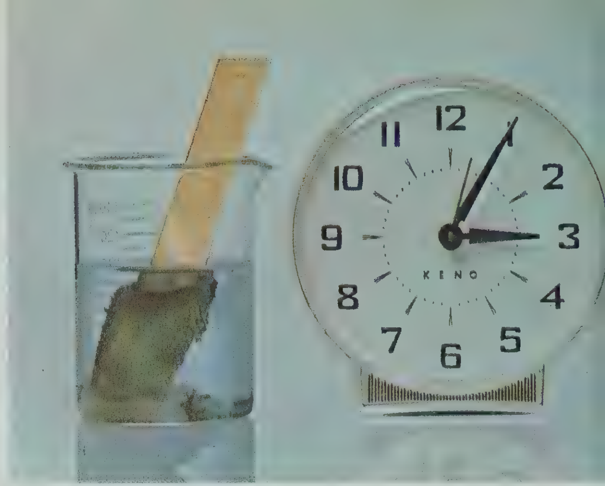
Some metals tend to react rapidly with other elements. Other metals only react slowly. And still others seldom react at all. A pattern of reactivity exists among the metals.

Can you see a pattern of reactivity in the following set of experiments? Each experiment involves placing a piece of one metal into a solution that contains a compound of another metal.

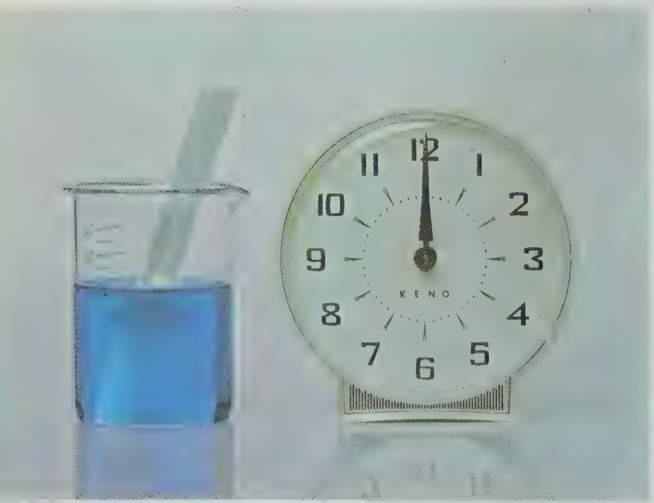
In figure 18•16a, an iron strip has been put into a solution that contains copper sulfate, a compound of copper. Figure 18•16b shows the strip in the solution a few hours later. Notice what has happened to the iron.



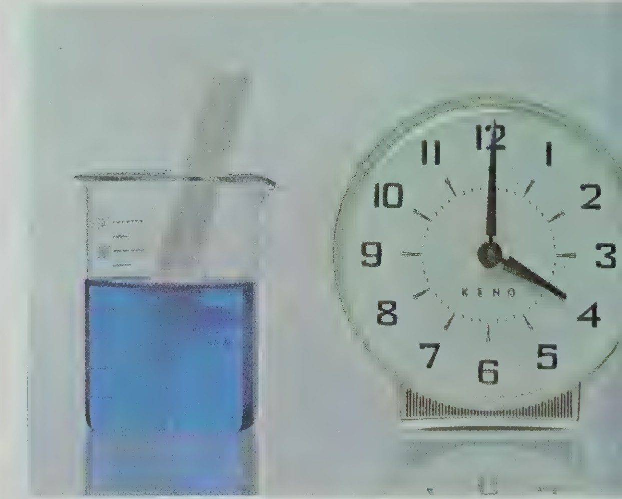
18·17a Copper strip in a solution of a silver compound.



18·17b Only three hours later, a grayish substance has formed on the copper.



18·17c Silver strip in a solution of a copper compound.



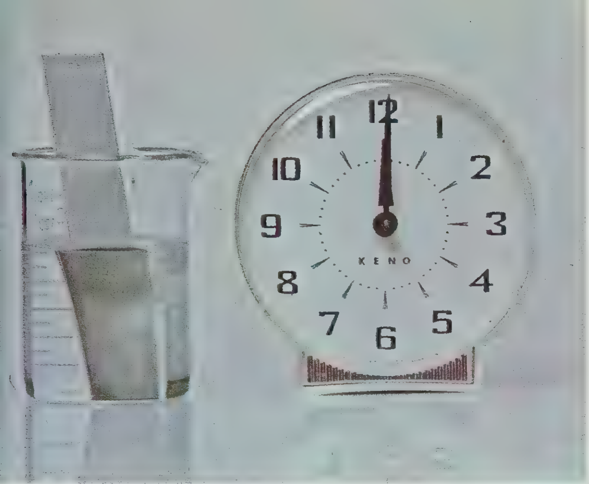
18·17d Four hours later, no change is visible.

Will the same sort of reaction take place if you put a piece of copper into a solution containing a compound of iron? The copper in figure 18·16c is in a solution of iron chloride. Figure 18·16d shows the copper in the solution after a few hours. Did anything happen to the copper?

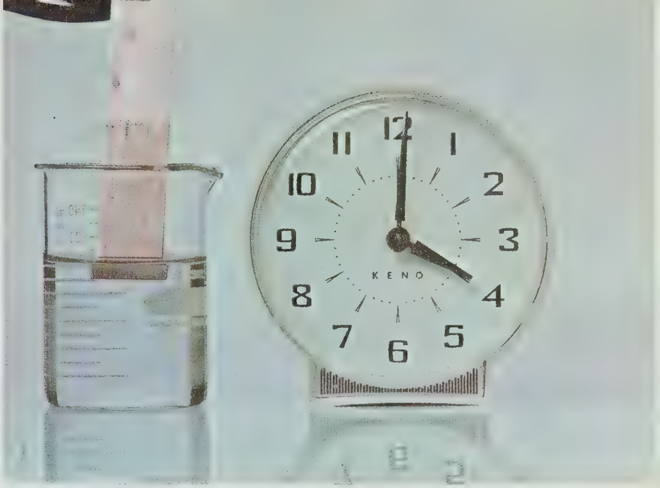
What will happen if you put the copper into a solution containing a compound of a different metal? It is being placed in a solution of silver nitrate in figure 18·17a. Notice what happens to the copper after a few hours (figure 18·17b).

What happens when a piece of silver is placed in a solution containing copper sulfate (figures 18·17c and d)?

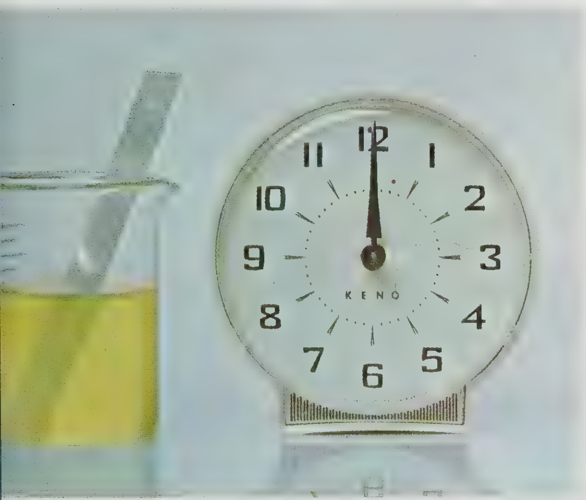
Do you notice any pattern? It would be a good idea to look at another pair of experiments before making a decision. Notice what happens when a piece of iron is placed in a solution containing silver nitrate (figures 18·18a and b).



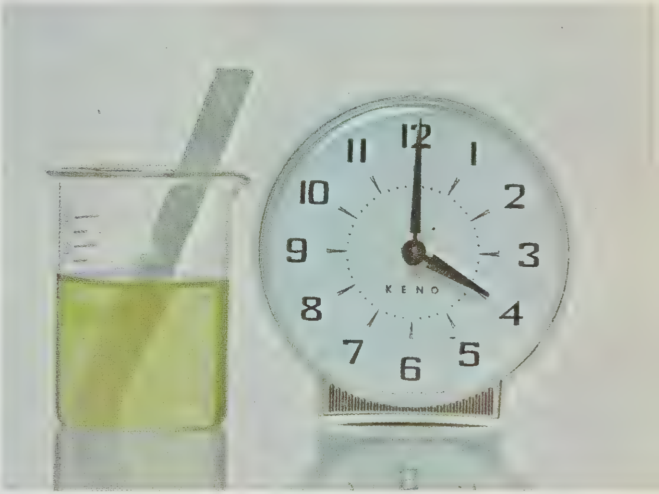
18·18a Iron strip in a solution of a silver compound.



18·18b A grayish layer has formed on the iron.



18·18c Silver strip in a solution of an iron compound.



18·18d No change is visible.

Does the same thing happen when a piece of silver is put into a solution containing iron chloride (figures 18·18c and d)?

There has been a chemical reaction in one of each pair of experiments. But it is not a combination reaction. That is, two substances did not combine to form a third. The iron strip in the solution containing copper sulfate had a layer of copper on it after a few hours. It is easy to see that copper came out of the solution and deposited on the iron strip.

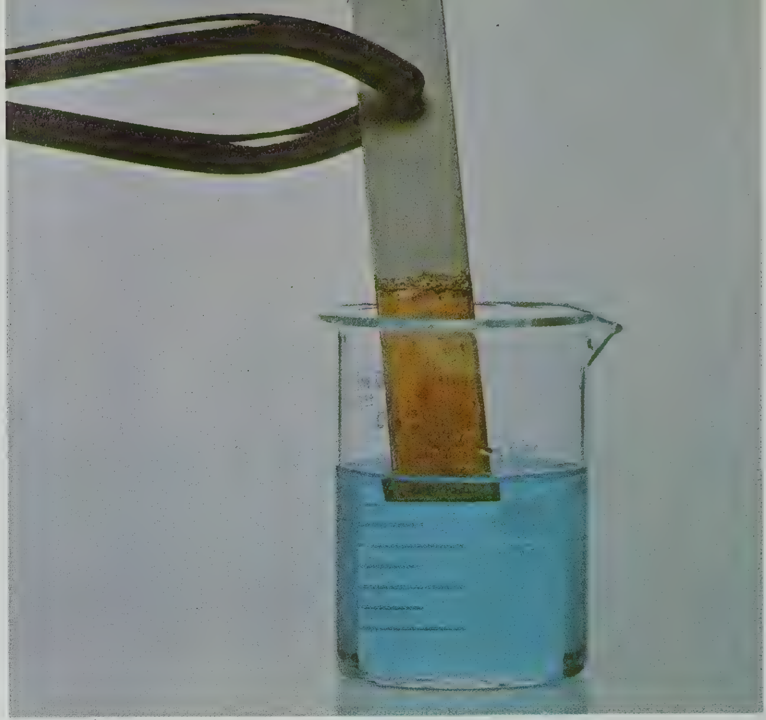
Something else happened that is not easy to see. In fact, you will have to observe another experiment before you can detect it. That experiment will be done on the solution in which the iron strip became coated with copper. It is a test chemists perform when they want to know if a compound of iron or copper is in a solution.

First the copper coated iron strip is removed from the solution. Then a solution containing sodium hydroxide is added to the beaker (figure 18•19b). When there is a compound of iron in the solution, a rust-colored substance precipitates (drops to the bottom of the beaker as a solid). When a compound of copper is in the solution, a blue-green substance precipitates. Notice what has happened in this case (figure 18•19c).

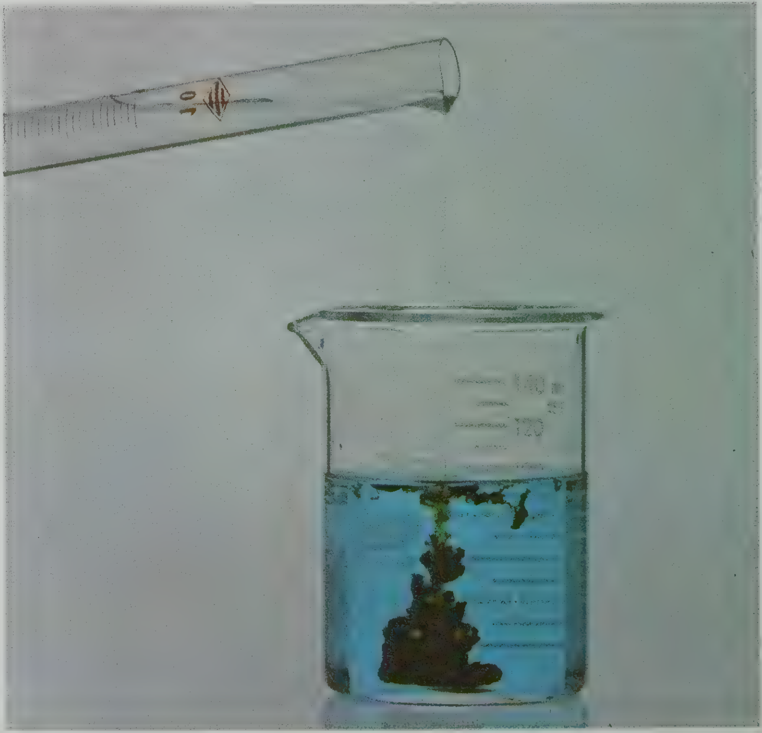
There must have been a compound of iron in the solution. When the strip was placed in the copper sulfate solution, iron went into the solution and copper came out. Chemists say that the iron displaced the copper from the compound, copper sulfate. This is a *displacement* reaction. One element has displaced another. It can be shown by an equation:

iron + copper sulfate ⟶
copper + iron sulfate

Displacement reactions show which of two metals is more reactive. If iron displaces copper out of the copper compound, iron is more reactive. What happened in the reverse reaction? Did copper metal react with iron chloride to displace the iron?



18•19a



18•19b

Now look back at figures 18·17 and 18·18. Which is more reactive, copper or silver? Iron or silver? Which is the most reactive of the three metals? The least reactive? Do your observations agree with the placement of the three metals in the displacement series in Table 1?

TEST YOURSELF

1. *List three metals that are not reactive.*
2. *List three reactive metals.*
3. *Name three metals that will displace copper from a solution of copper sulfate (Table 1).*
4. *Name one metal that will not displace copper from a solution of copper sulfate (Table 1).*

Table 1

Displacement Series

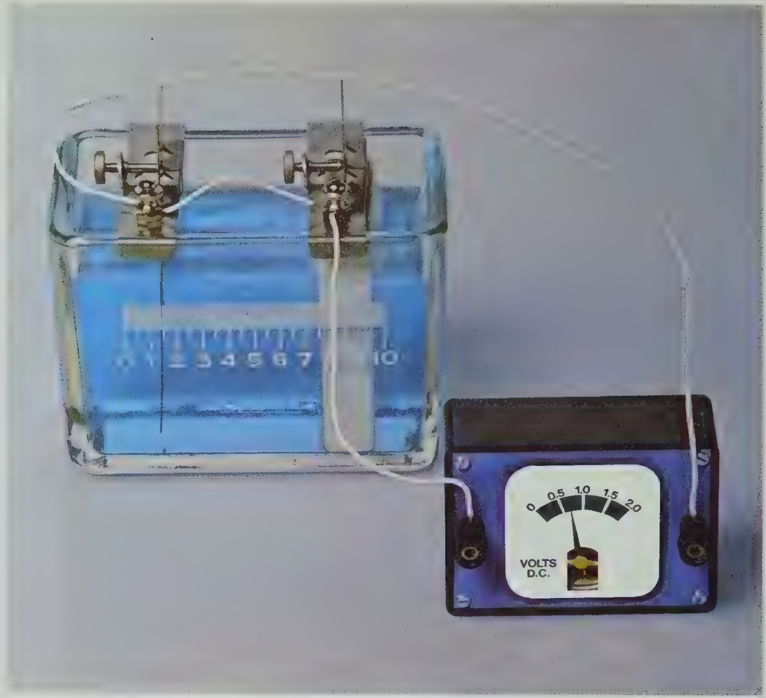
Order of reactivity
Magnesium—most reactive
Aluminum
Manganese
Zinc
Chromium
Iron
Cobalt
Nickel
Tin
Lead
Copper
Mercury
Silver—least reactive

18·19c

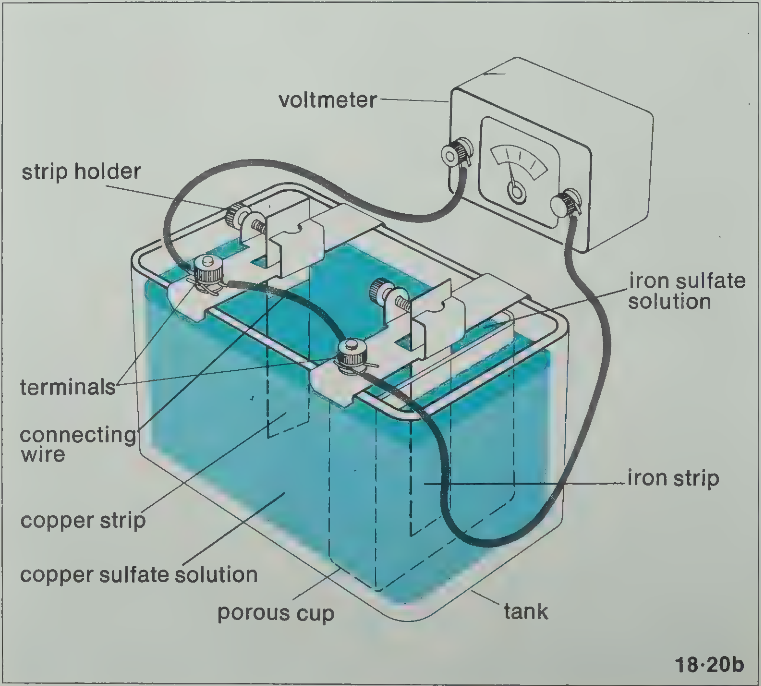
A strip of metal placed in a solution containing a compound of a less reactive metal displaces the less reactive metal from solution. But that is not the only way that a metallic displacement reaction will take place. Notice what happens in the following experiment (figure 18·20).

A strip of copper is placed in a clear glass tank which contains copper sulfate solution. A strip of iron is placed in a porous cup which contains iron sulfate solution. The cup is then immersed in the tank of copper sulfate solution. Thus, each metal is in a solution of one of its own compounds. These solutions are touching in the pores of the cup although they are kept from mixing.

The metal strips are connected by a wire made of a substance that conducts electricity. A voltmeter is attached in a parallel circuit with the metal



18·20a



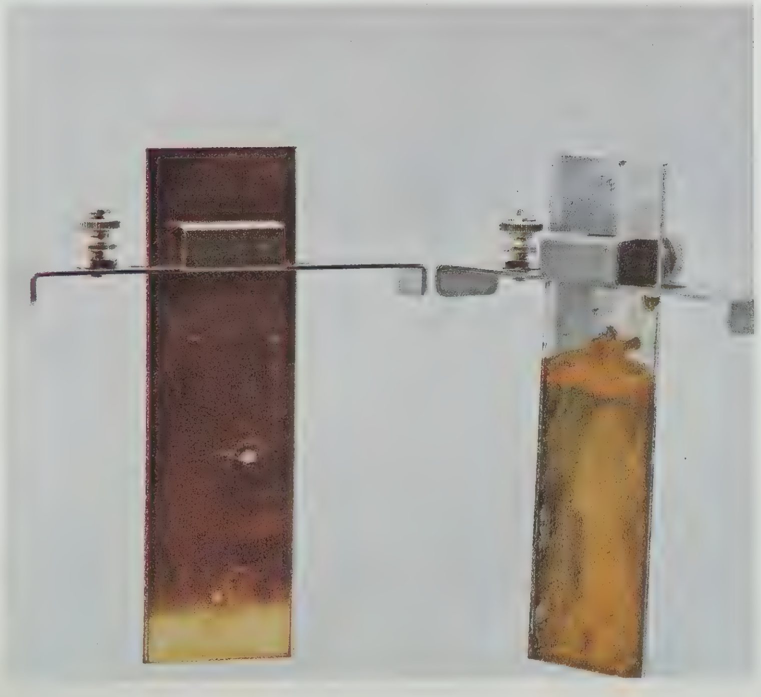
18·20b

strips. This arrangement is called an *electrochemical cell* (figure 18·20).

Look closely at the metal strips after the reaction has taken place for about 4 hours. Is there still a current? Notice what has happened to the iron and copper strips. The chemical reaction for this cell is the same as the reaction when an iron strip is put into copper sulfate:

iron + copper sulfate ⟶
copper + iron sulfate

In the electrochemical cell, the displacement reaction has not only made chemical changes. It has produced some usable electric current.



18·20c Notice that the iron strip looks rusty. Also notice the flecks of shiny copper on the copper strip.

18·21a

18·21b

Notice what happens when the iron in iron sulfate solution is replaced by zinc in zinc sulfate solution (figure 18·21a). Does the same thing happen when the porous cup contains a strip of iron in iron sulfate solution and the tank contains tin in a tin chloride solution? The same type of reaction takes place when you use other metals, as long as each metal is in a solution containing one of its own compounds.

Compare the voltage produced by all of the cells. Can you relate the difference in voltages to the reactivity of the metals in the cells? Can you relate it to the position of the metals in the displacement series (Table 1)? How would the voltage produced by a magnesium-copper cell compare to the voltages produced by the cells in figures 18·20 and 18·21?

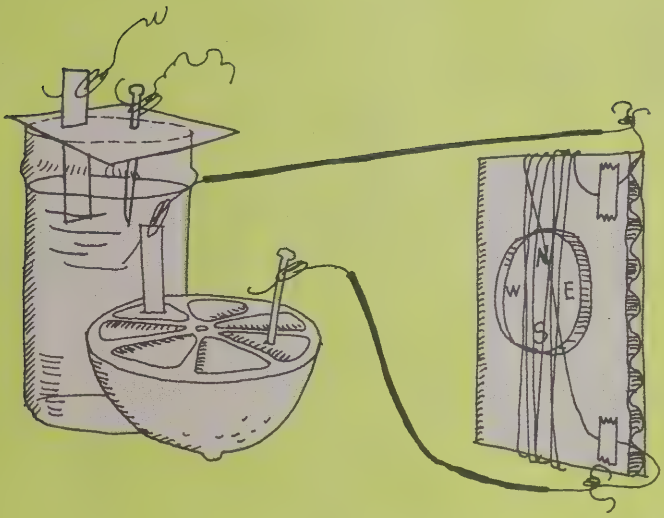
Every one of the metals in Table 1 can be made part of an electrochemical cell with every other one. The voltages produced depend on the distance between the reactivities of the two metals. For example, magnesium and silver are farthest apart on Table 1. So they would produce the highest voltage. All other combinations would produce a lower voltage.

Only one of the cells you have been studying has ever been used for practical purposes. The others are expensive and it is difficult to make the cell work the same way each time. However, a cell exactly like the one with copper and zinc in solutions of copper and zinc sulfates was common for many years. It was first used by an Englishman, John Daniell, and is named after him. The Daniell cell produced the electric current to run some of the early railroad telegraphs.

TEST YOURSELF

1. *What are the parts of an electrochemical cell?*
2. *Which two metals will produce the highest voltage in an electrochemical cell?*

ON YOUR OWN



Batteries

You can make your own battery with the following:

- 2 iron nails
- 2 aluminum nails (or 1 aluminum can top)
- 1 tin can top
- Water
- Salt
- 1 fresh lemon
- Baking soda
- Borax
- Simple compass galvanoscope (chapter 7, page 165)
- Copper bell wire
- 3 glasses of water
- 1 10-cm (3-in) cardboard square

Clean each of the pieces of metal. Rub fine sandpaper on the surface of the metal. Then wipe away any excess dust. Cut 1-cm-wide strips out of the center of the aluminum and tin can tops. Clean any coating off the aluminum or tin.

Strip the coating from two 10-cm lengths of copper bell wire. Clean the wire and bend each piece so it is shaped like a paper clip.

Dissolve about 2 tablespoons of salt in a glass of water. Use the wire to attach an iron nail to one terminal of the galvanoscope and a piece of aluminum to the other terminal as shown. Place the metals in the salt water and watch the galvanoscope to see if there is a current.

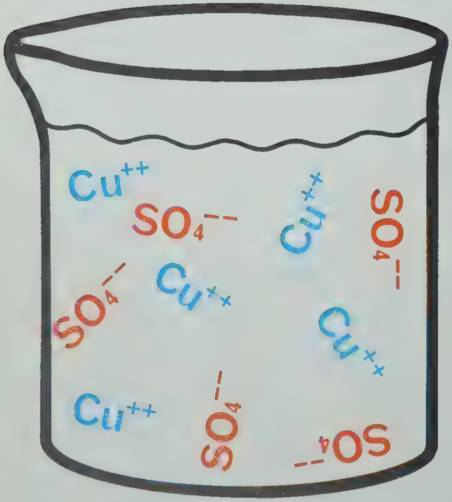
Dissolve about 2 tablespoons of baking soda in the second glass of water and 2 tablespoons of borax in the third. Place the iron and aluminum in the baking soda solution and watch the galvanoscope. Repeat the activity using the borax solution. Then push the metals into half of a fresh lemon. Is a current produced in any of the cases?

Repeat the above activities using several combinations of metals. You might try the bent copper wire and the iron nail, the bent copper wire and the aluminum, the bent copper wire and a strip of the tin can, and any others you think of.

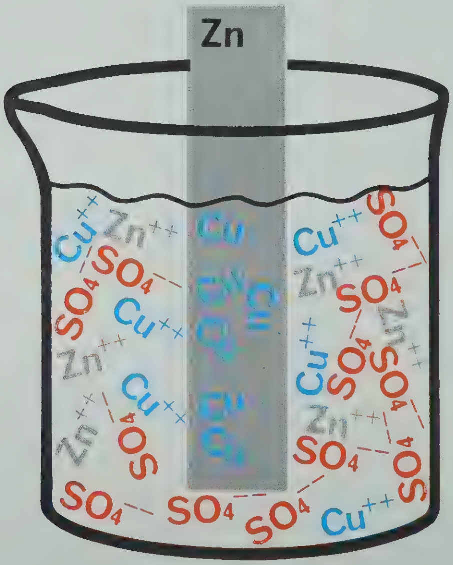
From Atoms to Ions

Exactly what happens in a displacement reaction? Let's start with the nucleus of an atom. It carries a positive charge. Outside the nucleus there are enough negatively charged electrons to make the atom electrically neutral. But an atom does not remain neutral in all situations.

An atom of one element can pull an electron away from an atom of another element. When this happens, both atoms are no longer neutral. The atom that lost the electron becomes positively charged. The atom or group of atoms that attracted the electron becomes negatively charged. These atoms, or groups of atoms, that have an electric charge are called *ions*.



18·23 Copper sulfate dissolved in water. Copper ions (Cu^{++}) and sulfate ions (SO$_4^{--}$) are moving about freely.



18·24 Zinc, the more reactive metal, pushes copper out of copper sulfate solution. Neutral copper atoms (Cu) deposit on the zinc strip. Positive zinc ions (Zn^{++}) go into solution.

The formation of ions (*ionization*) takes place in a displacement reaction. For example, we can look at the reaction that takes place when a strip of zinc is placed in a solution of copper sulfate. Copper sulfate is made up of positively charged copper ions and negatively charged sulfate ions. When copper sulfate crystals are dissolved in water, the ions separate and move about freely (figure 18·23).

Zinc is an element which reacts with other substances more readily than does copper. The electrons outside the zinc nucleus are not as firmly held as those outside a copper nucleus. So it takes less energy to pull electrons away from the zinc nucleus than from the copper nucleus.

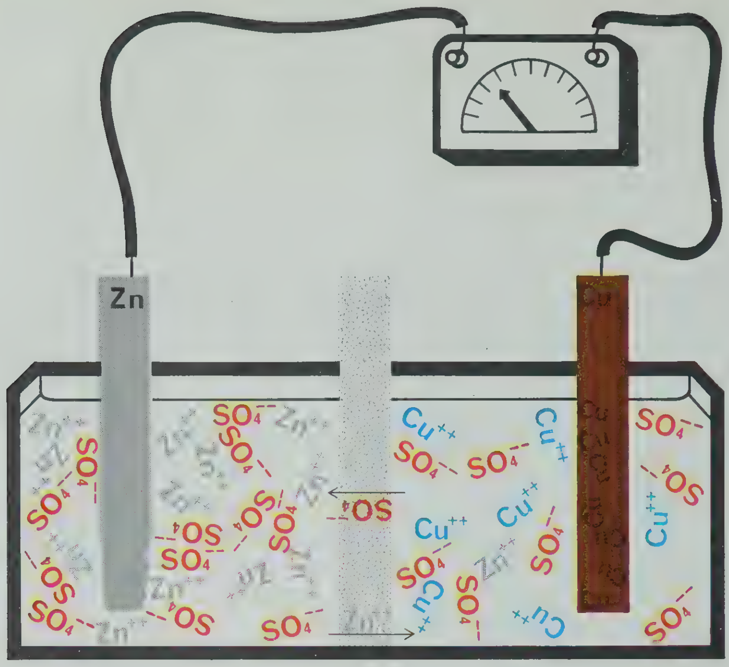
A displacement reaction takes place when a strip of zinc is placed in a solution of copper sulfate. Positively charged copper ions are moving freely through the solution. Whenever one of these ions brushes against the zinc strip it pulls two electrons away from a zinc atom. Once the copper ion gains these electrons, it is again a neutral copper atom. As a copper atom it is not soluble in water, so it is deposited on the zinc strip.

The zinc atom that has lost the two electrons to the copper becomes a positively charged zinc ion. It is now soluble in water. So it leaves the zinc strip and moves freely through the water.

The above reaction occurs all at once. Thus the solution is always electrically neutral. The positive charge of the zinc ions and copper ions in the solution is balanced by the negative charge of the sulfate ions. The equation for this reaction is:

$$\text{zinc} + \underset{\text{(solution)}}{\text{copper}^{++}\ \text{sulfate}^{--}} \longrightarrow \text{copper} + \underset{\text{(solution)}}{\text{zinc}^{++}\ \text{sulfate}^{--}}$$

The ion-formation model can also be used to study what happens in an electrochemical cell. The cell is divided into two halves by a porous barrier. One half of the displacement reaction takes place on each side of the barrier.



18·25 Reactions in an electrochemical cell.

On one side, a strip of zinc is hanging in a water solution of zinc sulfate. On the other side, a strip of copper is hanging in a solution of copper sulfate. The copper strip is connected to the zinc strip by a conducting wire.

At the zinc strip, the zinc atoms lose electrons to become positively charged zinc ions that go into solution. But in this case the zinc strip is in a solution of zinc sulfate. There are no copper ions next to the zinc to attract the freed electrons.

These electrons move through the conducting wire to the copper strip hanging in copper sulfate solution. The positively charged copper ions in the solution are in contact with this strip. These ions attract the electrons that crossed the conducting wire from the zinc strip. In this way the copper ions become neutral copper atoms.

The copper ions that have become neutral copper atoms deposit on the copper strip. The zinc atoms that have become zinc ions enter the solution. In the solution, the excess of positively charged zinc ions attract negatively charged sulfate ions through the pores in the barrier. Thus the solutions on both sides of the barrier remain neutral.

All of these reactions take place at the same time. The electrochemical cell provides a current until all the zinc is used up or no more copper ions are left.

ON YOUR OWN

Automobile batteries

Use any reference books or catalogues you can find to look up the parts of an automobile battery. Find how the automobile battery works. Where does the displacement reaction take place?

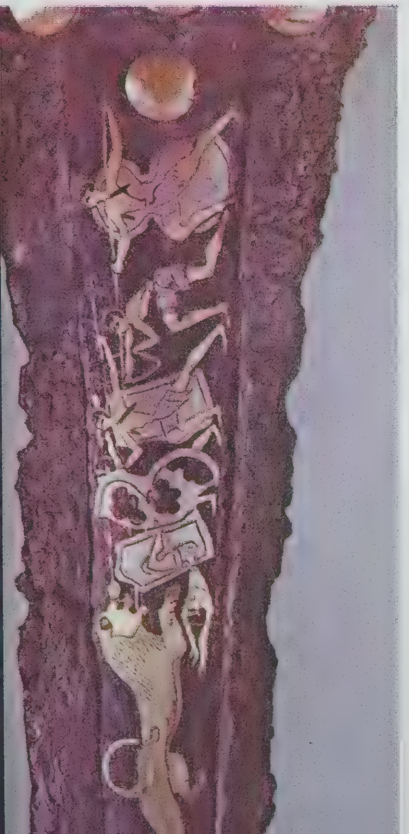
The discovery of metals and some uses for them

From the Stone Age to the Foundry

If our prehistoric ancestors had not begun to learn about the behavior of matter, we might still be huddling in caves, depending on wild fruits and berries for food. After discovering fire, perhaps a million years ago, they learned that stone can be chipped into very good tools and weapons. Then about 9,000 years ago, perhaps in Asia Minor, people learned that metals make better tools that last longer.

In nature, metals are usually combined with other elements in a form called ores or minerals. The metals can only be freed from their ores by heating (*smelting*) or chemical treatment. So early people first learned to use those metals they could recognize by sight. Such uncombined metals are called native because they occur in nature as metals rather than as ores or minerals. There are only three of these in more than very small amounts—gold, silver, and copper.

18·26 Bronze dagger with gold inlay (16th century B.C.). Bronze, a mixture of copper and other metals, is stronger than pure copper.



Gold

Some authorities think copper was the first metal used. But others suggest gold was noticed first. Gold doesn't tarnish easily and was probably found as bright, glittering nuggets or dust in stream beds. The first toolmaker who picked up a gold nugget must have been disappointed because the material could not be chipped into a spearpoint or arrowhead. Gold can be shaped by pounding with a stone. But the metal is too soft for making good tools and weapons, except small items such as pins or fishhooks. Yet we do have evidence that ancient peoples prized gold.

When these people could no longer find nuggets, they collected gold dust. Their means of collecting it is believed to be the basis for the legendary Golden Fleece in Greek mythology. They passed water containing sand and gravel from stream beds over sheepskins containing the fleece. The gold was much denser than sand or gravel. So it settled into the fleece and stuck to the wool grease that naturally coats each hair.

18·29 A historic map of the Middle East showing some of the locations at which ancient metal objects have been found.

18·27 Native copper.

Copper

Sometime before 5000 B.C. our human ancestors noticed certain greenish masses. These were either on the ground or in walls of canyons cut by rivers. If they scratched the surface of these masses, they found the green colored material was only a film covering a bright reddish metal. The metal was copper. The film forms because copper reacts with substances such as oxygen, carbon dioxide and sulfur in air and water. The film protects the metal from further reaction.

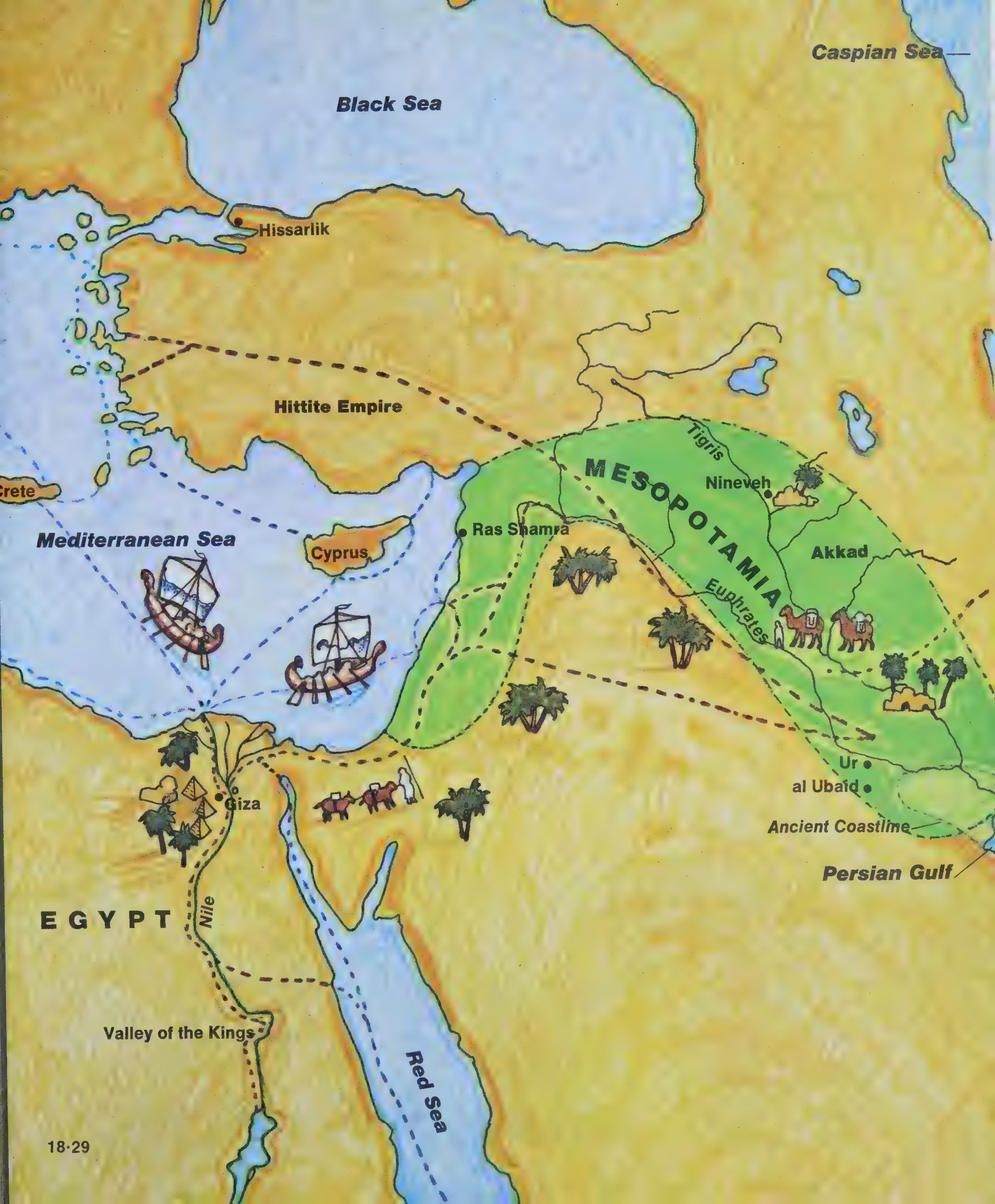
When supplies of copper on the surface of the earth became scarce, the ancients dug mines. At first their tools were crude, consisting of things such as picks made of forked tree branches or antler horn. Sometimes fires were set in the mines to crack the solid rock walls. Heat caused the top layer of the rock to expand faster than the rest. This caused the rock to crack. Sometimes, the hot rock was doused with cold water. Then the top layer contracted faster than the rest and caused more cracking.

Apparently fire was used to mine copper by early inhabitants of America, too. The world's largest deposits of native copper are in northern Michigan. About 5000 pits chipped out of solid rock can be seen there. When found, many of the pits still contained stone hammers and remnants of charcoal. New research methods have indicated that the copper deposits were worked by American Indians as early as 4000 B.C.

We know that metal was being smelted in Asia Minor by this time, but we can only guess how it began. Pottery has been made since about 6000 B.C. This required firing at very high temperatures. So we know that the ancients knew how to build hot fires.

We suspect that copper ore somehow got into one of these fires. Some experts think that the ore was malachite, which is a green copper carbonate ($Cu(CO_3)_2$). Ancient people carved malachite into works of art and ground it for use as a pigment in paints. If a chunk of malachite fell into a hot fire, copper metal could have been left in the ashes after the fire cooled.

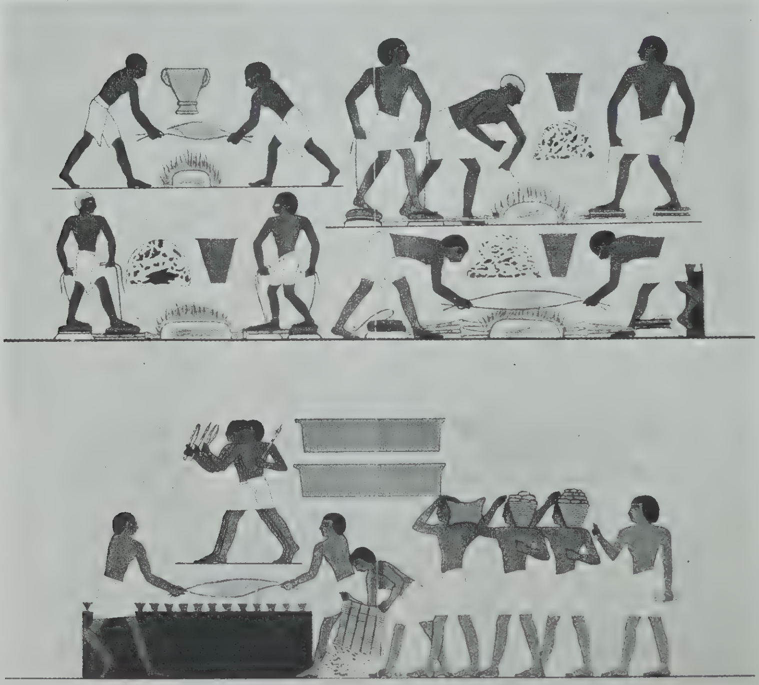
18·28 Spearheads beaten out of native copper from the Lake Superior region. These belong to the North American archaic period which ended in 1500 B.C.


Caspian Sea
Black Sea
Hissarlik
Hittite Empire
Tigris
MESOPOTAMIA
Nineveh
Crete
Mediterranean Sea
Ras Shamra
Cyprus
Akkad
Euphrates
Ur
al Ubaid
Giza
Ancient Coastline
Persian Gulf
EGYPT
Nile
Valley of the Kings
Red Sea

18·30 Bronze head of Sargon of Akkad (around 2350 B.C.) found in the excavation at Nineveh.

People soon learned to recognize minerals containing copper and started to build smelters. Perhaps they made hotter fires by surrounding them with walls of baked or sun-dried clay. And they could have placed the fire over a clay-lined pit to catch the molten metal. Then, they might have stacked alternate layers of charcoal and ore within the walls around the fire, much like the layers of a cake.

The discovery that a draft made the charcoal burn faster and produce more heat was an important step forward. At first, the smelter might have been placed on the side of a hill where strong winds were frequent. Soon crude air blowers were made from whole animal skins with neck, tail, and two legs tied. A clay tube could have been inserted into the third leg to blow out the air.



18·31 This ancient Egyptian wall painting shows smelting of gold ore. Similar methods might have been used with other metals. Egyptians placed the ore over a fire and stirred it during heating. They used foot bellows to pump air into the fire, making it hotter. Then they lifted the melted gold from the fire and poured it into molds.

And the fourth might have served as a valve to permit fresh air to enter the skin. Then by squeezing the skin, air could be forced through the clay tube into the bottom of the fire. After the fire was out, and the metal cooled, it was removed from the pit and hammered into shapes.

The people who removed the metal from the pit may have noticed that shapes of the cold metal and those of the pits were always similar. The idea of casting metals into shapes might have come from such observations.

Molten metal was poured into shallow open molds of stone or pottery having the general shape of the article to be made. Castings made this way were not good enough to be used as tools because one side was flat. They still had to be hammered, but much less time and effort were needed.

Rounded objects were sometimes cast by tying together two pieces of shaped pottery or stone and pouring molten metal into the center. Such objects had to be of solid metal and were heavy and wasteful of metal. Soon core-casting was invented. For this, a small mold or core was nested inside a larger mold and metal was poured into the space between. When the outer mold was broken away, a hollow core-filled shape was obtained. There is evidence that this process was common in Mesopotamia by 3000 B.C. (figure 18·29).

The ancients kept improving upon their smelting skills. Eventually, probably by chance, they learned how to make a mixture of metals that had some useful properties. That mixture was bronze. Bronzes are alloys of copper with other metals such as arsenic, antimony, and tin which at first were probably impurities in copper. The first bronzes contained arsenic. Soon, probably because arsenic is so poisonous, other bronzes, mostly of tin, came into use. These were superior to copper because they melt at lower temperature, are more easily cast, and are stronger.

Tin

Like gold, tin can be found in stream beds. An ancient searching for gold might have picked up heavy black nuggets of tin oxide called cassiterite. Smelting cassiterite is simple. It need only be mixed with charcoal and heated. Yet, one of the earliest tin artifacts (objects made by humans) known is a strip of tin dated near 600 B.C. This was found among the wrappings of an Egyptian mummy.

The importance of tin in bronze was recognized as early as 2000 B.C. At that time the inhabitants of Hissarlik, a city that stood on the same site as ancient Troy, obtained both tin and copper from central Europe. Hissarlik then established trade with Egypt, which was without tin. It also traded with Crete where the magnificent Minoan civilization flourished.

In 1800 B.C. Egypt, because of political misfortunes, ceased to be a customer. Hissarlik then began to trade with Spain, which had her own tin supplies. Soon Spain made her own bronze. And when Spain's tin supplies were used up, bronze centers moved through France to England, where other tin mines had been discovered.

18·32 Hammered copper panel from above the doorway of a temple at al-Ubaid near Ur (around 2000 B.C.).

18·33 Battle axes made of meteoric iron (around 1000 B.C.)

Iron

In many languages, the word for iron is related to that for "heaven-sent." The first iron used by ancient peoples probably came from a certain kind of meteorites, called *irons,* which contain up to 95 percent iron. The rest is mostly nickel and sometimes a little cobalt.

Smelted iron usually does not contain much nickel. Therefore, when fairly large amounts of nickel are found in an ancient iron artifact, the iron is thought to be from meteorites. A dagger found in Egypt and dated about 3500 B.C. has been found to contain 11 percent nickel. Iron beads of about the same date contain about 7½ percent nickel. The iron in these is, then, likely to be from meteorites.

Iron smelting probably was invented by the Chalybes (kal′i bēz), subjects of the Hittites, a people who lived in Asia Minor near the upper Tigris and Euphrates rivers (figure 18·29). This happened in perhaps 2000 B.C., long after copper smelting was known. This delay might be because iron must be smelted at higher temperatures. (Copper melts at 1083°C and iron at 1535°C).

Iron might have been found in the ashes of pottery kilns or copper smelters as a porous, ugly mass filled with cinders and waste materials. The first one who tried to hammer this mass into a tool certainly wasted time. Such impure material could not be worked into a good cutting edge no matter how much it was hammered.

18·34 Dagger and sheath of gold and iron found in the tomb of Tutankhamen (around 1350 B.C.) in the Valley of the Kings.

A great step forward happened when someone discovered that if the ugly mass was heated repeatedly in a charcoal fire and hammered, it became harder and superior to bronze. This discovery is believed to have taken place shortly before 1900 B.C.

Now we know that repeated contact with charcoal followed by hammering gradually works carbon into the surface of the red-hot metal. This process is called *carburization*. It produces a film of steel around an iron core.

How the iron was handled during hammering is a mystery. No tools suitable for that purpose have been found. Copper and most copper alloys soften between 400°C and 800°C and would have become useless for handling red-hot iron. The temperature of the iron is above 750°C. One suggestion is that wet tree branches were used to handle the hot iron.

At first, ancient people treasured iron and made it into ornaments and jewelry. For example, the tomb of Tutankhamen of Egypt, dated at about 1350 B.C., contained a dagger of smelted iron placed in a position that showed it to be a prized possession. The dagger was probably a gift from a king of the Hittites because at that time iron working was unknown in Egypt. The tomb also contained a welded iron headrest. This is of special interest because welding requires a high temperature of about 1350°C.

The Hittites seemed to have kept their knowledge of iron working secret. When their empire fell in 1200 B.C., iron workers migrated to other parts of the world, taking their art with them. By 1000 B.C. the art had spread to Greece, Crete, and then through the Balkans into central Europe and regions east of the Alps. There, better grades of ore were available. Thus better grades of iron could be made.

But two other valuable processes still had to be discovered. *Quenching,* which involves rapidly cooling the hot metal, was developed in Egypt between 900 and 700 B.C. Quenching is usually done by plunging the hot metal into water. The resulting steel is hard and brittle.

Therefore the second process, *tempering,* is necessary. In tempering, quenched iron is heated to moderate temperatures and slowly cooled. This softens the steel just enough so that good nonbrittle cutting tools can be made. But the process was not mastered until ancient Roman times. The ancients probably tempered their steel by using a quenching process which lowered temperature more slowly than cold water.

Considering the tools they had to work with, the ingenuity of ancient people is almost unbelievable. They had accomplished so much by the advent of the Christian era that there was little change in metalworking for over 1600 years until the Middle Ages.

18·35 Golden bowl from Ras Shamra (1400 to 1500 B.C.). Note the hunting scene around the bowl.

Most automobiles are made mainly of steel, an alloy of iron. Since they are used out-of-doors in all sorts of weather, the steel tends to react with the substances in the air. That is, automobiles rust.

Rust flakes off the iron surface to expose more iron to the air. In this way the steel of the automobile is eaten away or *corroded*. Or it would be if the steel had not been treated to protect it against corrosion.

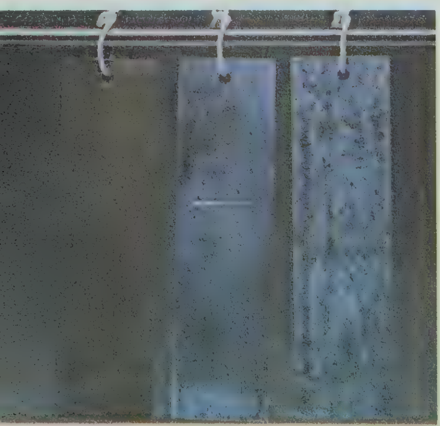
One method of protecting steel against corrosion is to coat it with zinc, or *galvanize* it. Two of the steel strips in figure 18·36 have been galvanized. Notice what has happened to the strips after they have been suspended above boiling water overnight. The first strip is bare steel. The middle one has a scratch in the center, and the last one has an unbroken zinc coating.

There is an explanation for these observations. The iron and the zinc of the middle strip have acted like the parts of an electrochemical cell. The more reactive zinc displaces the less reactive iron from any compounds it might form during corrosion. Thus the iron remains free metal.

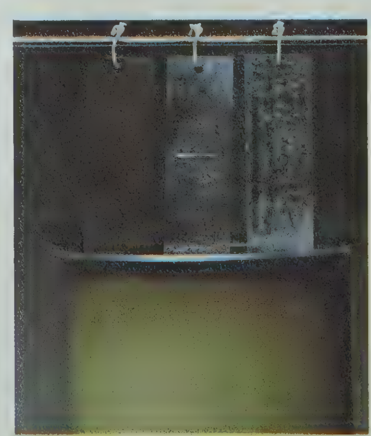
What do you suppose would happen to a strip of iron that had been coated with aluminum? Check Table 1 (page 467) to find how reactive aluminum is.

Another method used to protect steel against corrosion is *plating*, or electrochemically depositing a layer of another metal on it. Tin, copper, and chromium are often plated on steel parts of an automobile. How do you think they react in a corrosive environment (figure 18·37)?

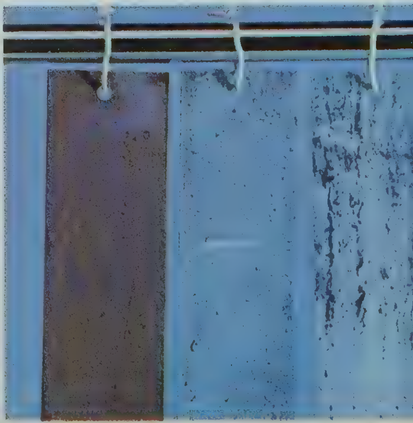
The method used most often to protect steel against corrosion is painting. The paint, like the plated metals, acts as a coating to keep air and water away



18·36a From the left, bare steel strip, scratched galvanized steel strip, and unscratched galvanized steel strip.

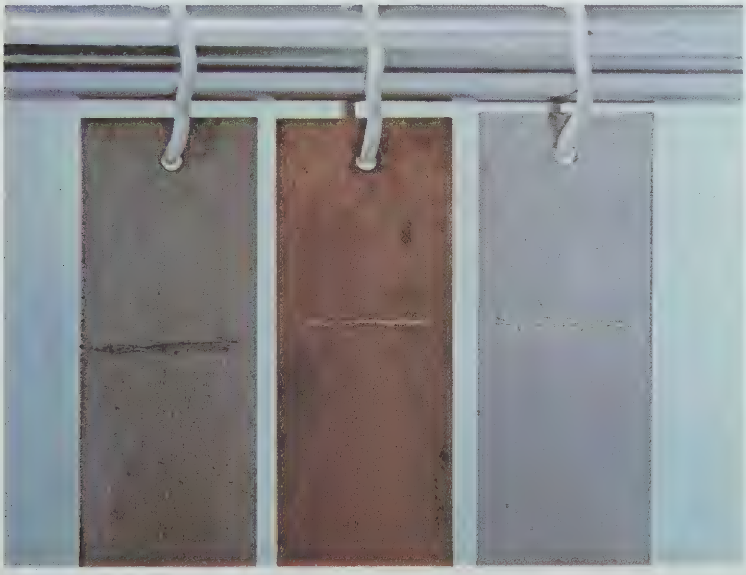


18·36b Using steam to rust the steel strips.



18·36c Bare steel has been pitted by rust. Both scratched and unscratched galvanized steel strips have not rusted, and the scratch is less visible.

18·37a Using steam to rust scratched steel plated with tin, with copper, and with chromium.



18·37b All the scratches on these steel strips have rusted. Note that the chromium plating has protected the scratches against rust better than either the tin or copper plating. Chromium, like zinc, is more reactive than iron in a displacement reaction. Another reason chromium protects the metal better is that chromium is harder to scratch.

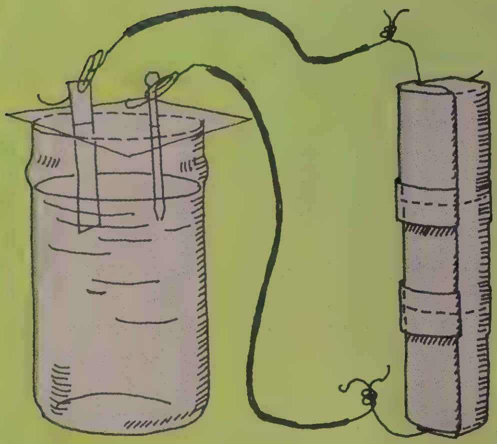
from the iron. If the paint surface is broken the metal below it is open to the atmosphere.

The paints used on bridges and certain steel buildings do more than act as coatings. They contain compounds of lead and zinc that are formulated to keep the metal from taking part in the chemical reactions of corrosion.

TEST YOURSELF

1. *Name three methods of protecting iron against corrosion.*
2. *Give one reason why zinc protects iron better than tin does.*
3. *What is corrosion?*
4. *In your own words, define plating and galvanizing.*

ON YOUR OWN



Adding electricity

You can find out what happens when you pass current into an electrochemical cell using the same materials as in the first activity of this chapter (Batteries, page 471. But you will need three D batteries attached as shown, in place of the galvanoscope.

Repeat the activities of the experiment on batteries in those cases where a current was produced. But attach the metals to the D batteries so that a 4.5-volt current passes through the circuit. Observe what happens as the current passes through each electrochemical cell for 5 minutes. Reverse the direction of the current and again observe what happens.

ON YOUR OWN

Corrosion protection

You can see how some common substances are protected against corrosion using these materials:

2 tin cans, 1 with a scratch
2 iron nails, 1 scratched
2 aluminum cans, 1 scratched
1 iron nail, completely coated with paint
1 bobby pin with rubber coating
1 bobby pin, uncoated
1 bobby pin, completely coated with paint
Steel wool, uncoated
String
Paper towel

Use string to hang each of the above items in a steamy bathroom. Or place each of them on the edge of the bathtub on a piece of wet paper towel. Look at them after 12 hours and after 24 hours. Which rusted? Where did they rust? How did the rust spread?

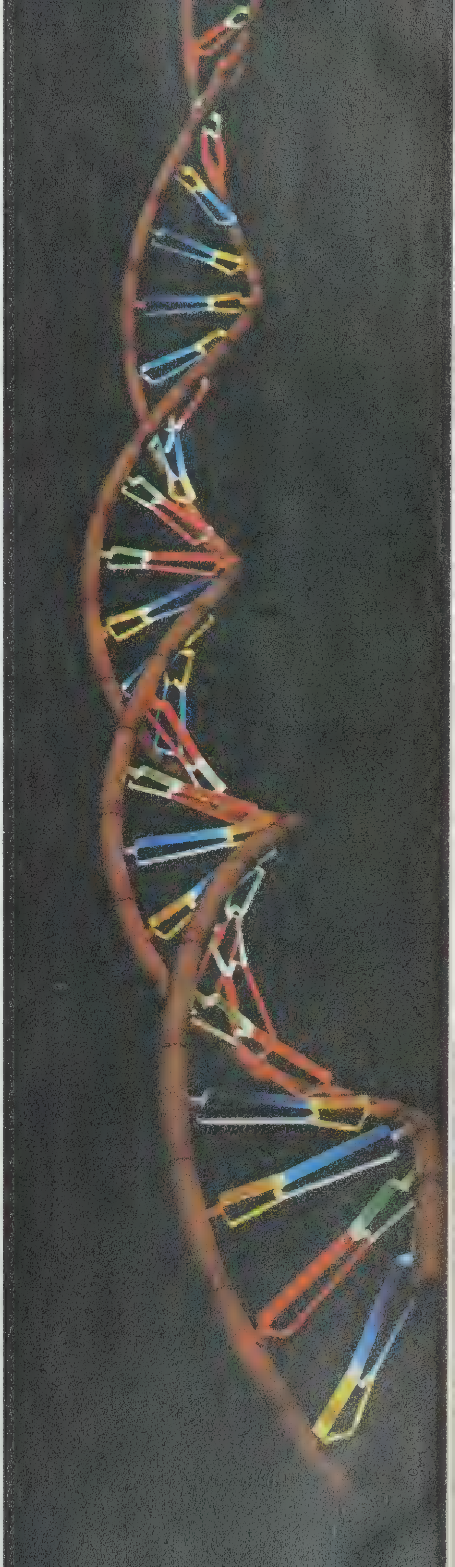
Chapter 19: Compounds of Life

19

All living things are made of compounds of the same elements. But the differences among living things are countless.

For many years these differences were thought to be connected with a "vital force." All living things and all of the molecules they are made of were thought to be controlled by something particularly living.

Ordinary chemicals like sodium chloride were thought to differ from the compounds of living things because they lacked the "vital force." Today we know better. But it took an experiment performed about 150 years ago to open the door to the present understanding of the compounds of life.



The Magic of Carbon

An explanation of the variety of "living" molecules

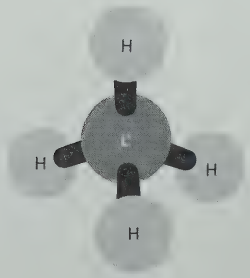
One day in 1828, a German chemist, Friedrich Wöhler (vė′lər), happened to heat an ordinary chemical called ammonium cyanate (NH_4OCN). When he looked at it after a while, he was surprised to find that the compound urea (NH_2CONH_2) had formed. Urea is found naturally in the urine of animals, including people. Wöhler had produced a compound of life without adding any "vital force." A new explanation was now needed for the differences between compounds usually found in living things and compounds found in minerals.

Scientists found that all of the compounds of living things contain the element carbon. Carbon also forms mineral compounds. Limestone and marble, for instance, are both different forms of calcium carbonate, $CaCO_3$. How is the carbon in these minerals different from the carbon in the compounds found in living things?

In the carbon compounds of living things, two or more carbon atoms are attached to each other. In mineral compounds, that does not usually happen. The molecules of living things contain chains of carbon atoms, dozens, sometimes hundreds, of atoms long. And they also contain compounds in which the carbon atoms link together to form a ring.

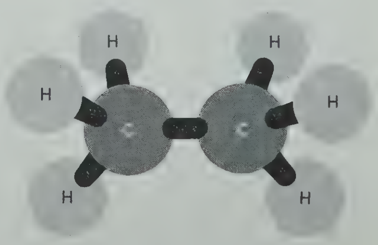
This ability of carbon atoms to link to each other is the reason for the great variety among the molecules of living things. The branch of chemistry that deals with the many ways that carbon links to carbon is called *organic chemistry*.

methane



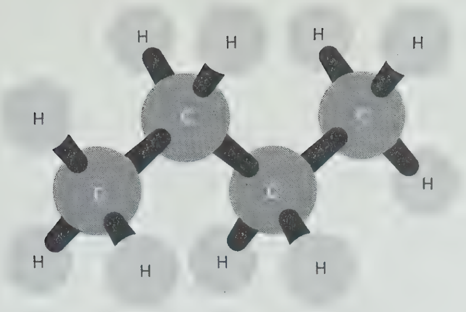
19·1a

ethane



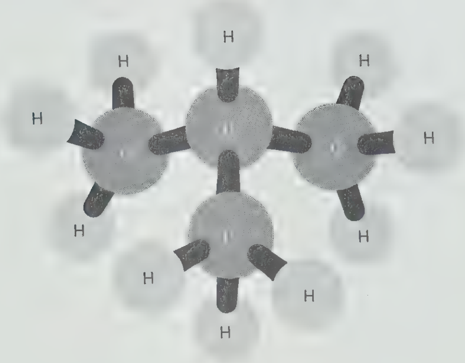
19·1b

butane



19·1c

isobutane



19·2 The same number of carbon and hydrogen atoms are attached differently in the isobutane molecule (C_4H_{10}) as in the butane molecule, also C_4H_{10}. So the two are different substances.

The simplest organic compounds, *hydrocarbons,* contain only carbon and hydrogen. They can be used to show how the carbon-carbon linkage can lead to such a variety of organic compounds. The simplest hydrocarbon is methane, CH_4. It has one carbon atom surrounded by four hydrogen atoms. The next simplest is ethane, C_2H_6 (figure 19·1).

The hydrocarbons become more complex as the number of carbon atoms in each molecule rises. But the variety of organic molecules is due to more than the rising number of carbon atoms in a chain. As soon as there are four carbon atoms in a hydrocarbon molecule, the chain of carbon atoms begins to branch. It is possible for one carbon atom to be linked to as many as four others.

A C_4H_{10} molecule having four carbon atoms in a row is shown in figure 19·1c. The molecule in figure 19·2 is also C_4H_{10}, but it is not the same substance. The two C_4H_{10} molecules have different physical properties. The compound with four carbon atoms in a row boils at —0.5°C. The branched chain compound boils at —10°C.

The possibilities for such combinations are practically endless. And they all contribute to the variety of living things.

Another reason for the variety of living things is that many units of smaller organic molecules join together to form chains

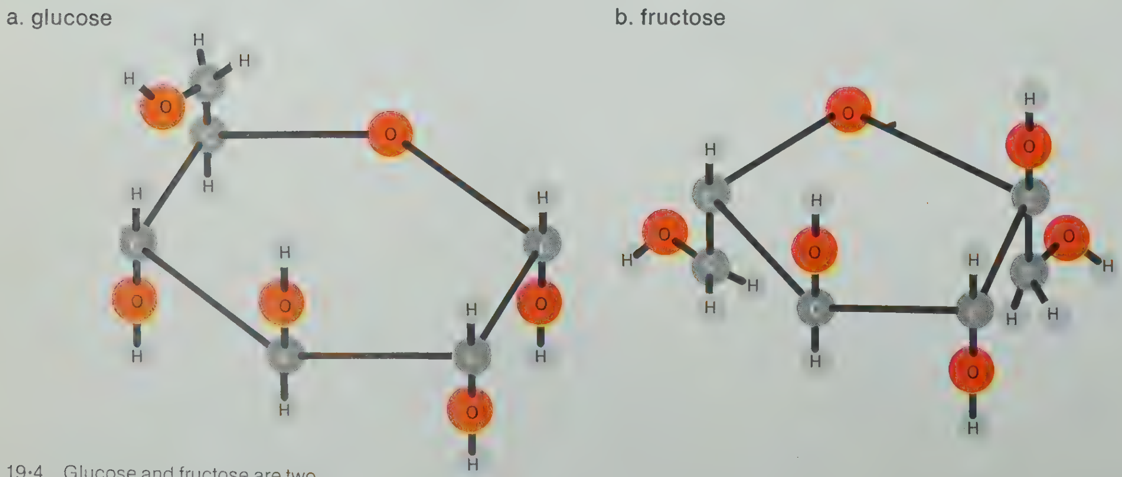
Molecules on a Chain

I'm hungry!

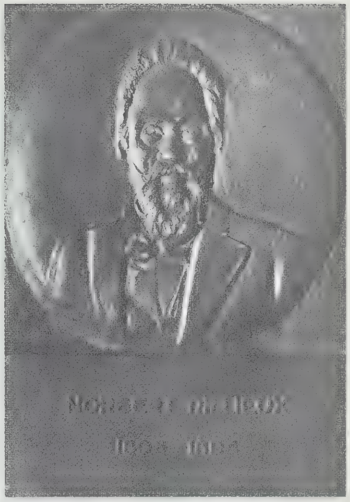
There's nothing like a bite out of a juicy red apple. Mmm, good! Did you ever stop to think that even an apple contains molecules? The apple is so sweet because it consists of sugar molecules. These sugar molecules in the apple are strung out together, the way beads are strung into a chain. They make up a foodstuff called a starch. In starch, the chains of sugar molecules are joined together to form very large, complex molecules. Such large molecules that are made up of many units of smaller molecules are called *polymers*. The polymer, starch, is made of many sugars.

Sugar itself is not a simple molecule. In fact, there are many different kinds of sugars (figure 19·4). All are sweet, though not equally sweet. And all are chemically similar, but not identical.

Sugar is an important chemical in the life processes. In your body, sugar is in part changed to simpler compounds. This reaction provides energy for your activities and heat to keep your body warm. Some excess sugar is changed chemically into fat and stored. Other excess sugar is changed into a polymer called glycogen. Glycogen is stored in your liver and can be rapidly changed back into sugar.


a. glucose
b. fructose

19·4 Glucose and fructose are two of the many simple sugars.



19·5 Norbert Rillieux was born in New Orleans. After being freed from slavery and educated in France, he returned to Louisiana. There he invented the Rillieux process of vacuum distillation of sugar cane juice. Better quality sugar could then be produced at less cost. Rillieux left New Orleans when he was required to carry a pass because he was black. He returned to France. There he worked with a famous archaeologist, deciphering Egyptian hieroglyphics.

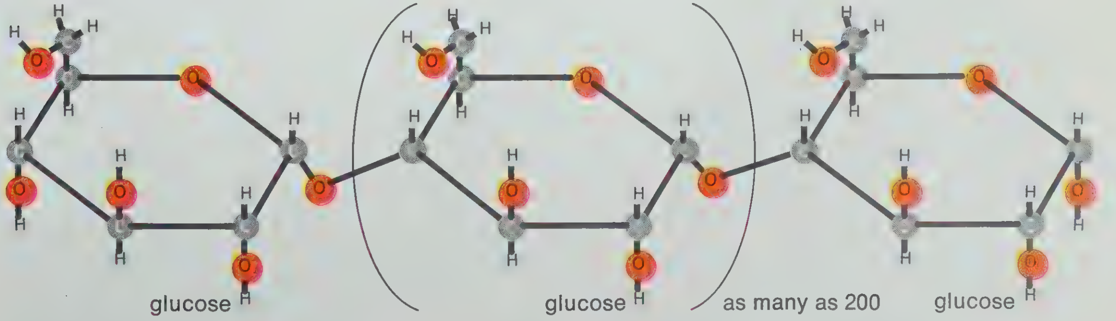
Most of the sugar that enters your bloodstream comes from starch foods you eat. Starch is stored by plants, much as glycogen is stored by animals. Plants change the excess sugar they produce during photosynthesis into starch. This starch is then stored in the plant.

Figure 19·6 shows one way sugars are connected in starch molecules. In some plants, the sugars which make up the starch are strung out like the beads in a string, forming long molecules. In others, the sugars are linked together more like the branches of a tree. Whatever the arrangement, all starches consist of thousands of repeated units of the smaller sugar molecules.

When you eat the starch—that juicy red apple, for instance—the polymer is broken down by digestion reactions into the individual sugar molecules. The sugar molecules are small enough to pass through the intestinal walls into your blood. Starch molecules are not. If your body does not need all the sugar, it *polymerizes* it (changes it into a polymer) again and stores it as glycogen.

Plants form yet another polymer of sugar, cellulose. Cellulose is different from starch because its molecules are linked together differently. Cellulose does not dissolve in water and is not broken down by human digestion. Therefore, cellulose is not absorbed but is eliminated by human beings. Some of our common domestic animals do have enzymes that allow them to break down cellulose molecules into sugar molecules. Cattle, sheep, and goats, among others, thrive on cellulose in the same way that humans thrive on starches.

19·6 Straight-chain starch molecule.

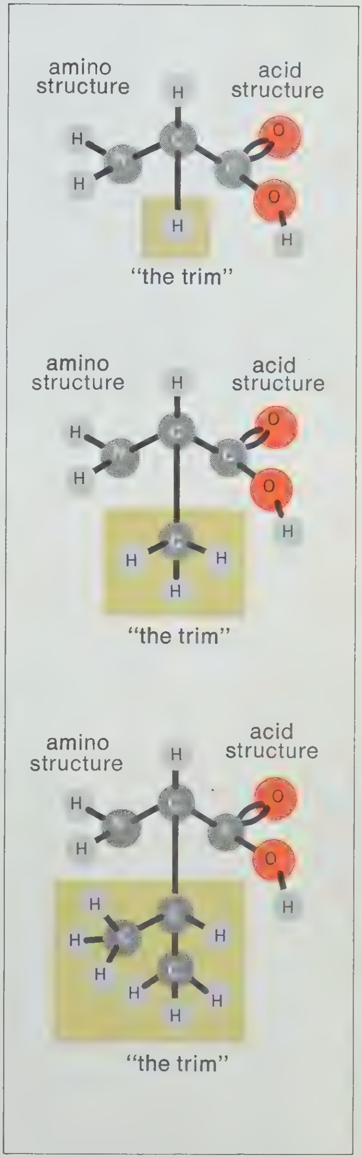


Make mine medium rare

Steak also consists of molecules that are strung together like beads in a chain. The polymers in steak are called proteins. Proteins are different from carbohydrates and fats. They contain nitrogen, and sometimes sulfur and phosphorus, in addition to carbon, hydrogen, and oxygen. The proteins are the basic building blocks of muscle, vital organs, eyes, skin, nails, and hair. They are more complex polymers than starches. Proteins are made up of varying combinations of about 20 simpler molecules called amino acids.

The amino acids are related to each other, yet each is slightly different. They are like the different makes of cars. Though the basic structure is alike, the trim is a bit different for each. All of the amino acids have the amino structure and the acid structure (figure 19·8). The rest of the molecule (the trim) differs in each of the amino acids.

19·7



19·8 Three different protein structures. Each has the same amino and acid structure. Only "the trim" changes.

Chemists are not sure how many different proteins exist in nature. The number is really limitless. With about 20 (some sources say there are up to 30) simple amino-acid units to choose from, there are very many different possibilities for the polymers. For a small protein of 20 or 30 amino-acid molecules, the number of different possible combinations is in the billions of billions. And for the proteins of muscles or other tissues, the number of possibilities is so large that it is hard to imagine.

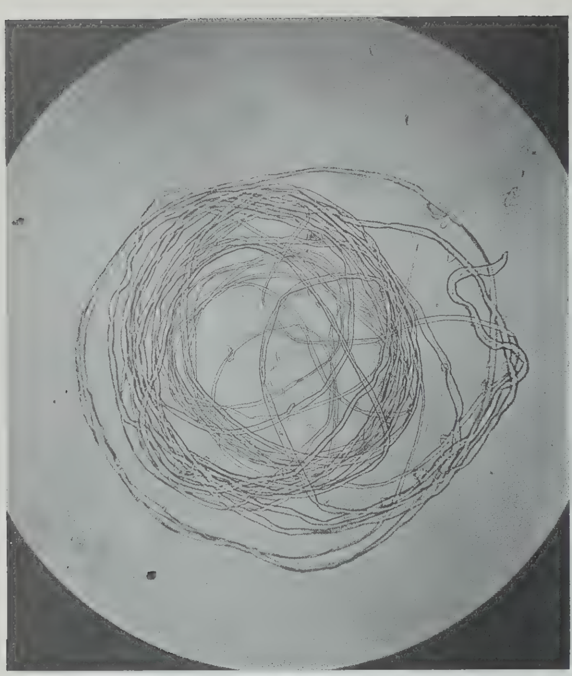
Proteins occur in certain plants as well as in animals. Peas and beans (not green beans) are among the few vegetables that are rich in proteins. Most vegetable proteins are incomplete; that is, they do not contain all of the amino acids needed to maintain human life or support growth. The protein of other plants, nuts and cereal grains in particular, do contain the amino acids needed for proper human development. And animal products such as milk, meat, fish, and eggs are rich in this kind of protein.

In some regions of the world there is a serious shortage of animal protein and a lack of knowledge about which plant proteins can be eaten to make up for this shortage. Many of the children in these regions suffer from brain damage and serious malnutrition diseases because of the lack of certain amino acids in their diets. This could be corrected by feeding them proper amounts of such proteins as the glycinin found in soybeans or the glutenin found in wheat, both of which contain the essential amino acids.

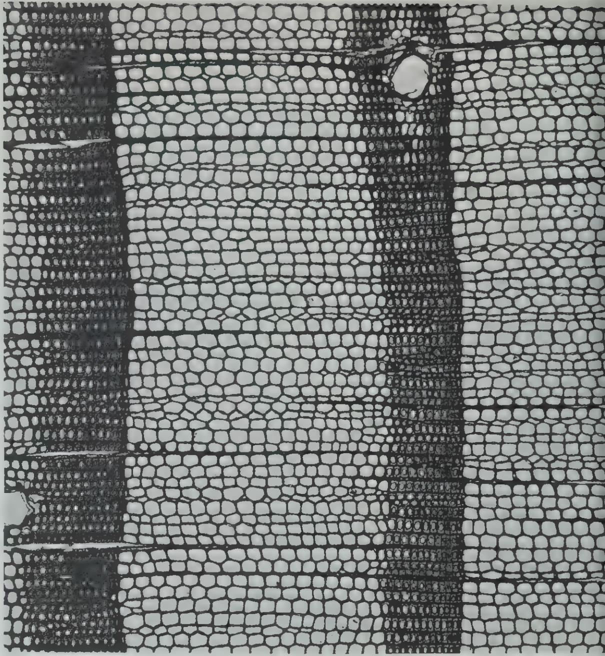
I'll wear mine

This evening's dinner might even be good to wear. Amino-acid and sugar polymers provide us with shelter and clothing as well as food. The amino-acid polymers, wool and silk, are basic clothing materials. And such luxury clothing materials as furs are also protein, along with everyday materials such as leather. But when it comes to everyday use, the sugar polymers outnumber the amino-acid polymers. The sugar polymer, cellulose, is the basic constituent of wood, cotton, linen, and paper.

The structure of cellulose polymers shows how they can produce these important compounds. In the spinning of cotton, for instance,



19·9 This cotton fiber is magnified 60 times. Notice how the shape of the fiber varies throughout its length.



19·10 This section of pine has been magnified 50 times. The cell walls are made of cellulose molecules.

small strands of fiber are curled together into longer and longer threads. But each of the fibers is itself made up of millions of molecules that are curled together in the fiber (figure 19·9). Long string molecules form the fiber, and long string fibers form the thread.

All of the cellulose fibers—cotton, linen, flax, hemp—are similar in this way. The individual cellulose molecules may be shorter or longer, more compact or more spread out in each fiber. As a result the yarn may be softer or tougher, smoother or coarser.

Wood does not consist of fibers (figure 19·10). The cellulose molecules form different kinds of solid structures in wood. The cellulose may be closer together to form hard wood or farther apart to form softer wood. There are all sorts of other compounds also mixed in with the cellulose. But the basic structure of wood is that of a polymer of sugar molecules which are arranged to give the characteristics of that particular kind of wood.

Paper is a highly refined wood. But not all varieties of wood can be used to make paper. The wood is cut, chipped, and ground into very short particles. These are stirred with water and purified by chemical treatment. The fine cellulose particles remaining are then deposited on a felt pad. The excess water flows away, and the moist layer of cellulose is passed between drying rolls. As the cellulose particles dry, they interlock to produce paper.

ON YOUR OWN

Breaking down starch

You can prove that saliva breaks down starch with the following materials:

Water
1 slice of bread
1 soda cracker
Cornstarch
Saliva
6 juice glasses or small jars
Iodine solution

Place ½ of the slice of bread in about 2 cm of water in a small jar. Put the cracker in 2 cm of water in another jar. Let them sit for about 10 minutes.

Pretend you are chewing something and, as the saliva collects in your mouth, spit it into the third and fourth small jars. Add a little water to the saliva in jars 3 and 4, and put some water in jars 5 and 6. Label the jars so you know which ones contain saliva.

Squeeze the water out of the bread so that the water remains in the jar. Remove the bread. Do the same with the cracker. Put about half of the bread water into one jar containing saliva. Put the other half into a jar containing water. Label both jars. Now put half of the cracker water into each of the last two jars.

Wait 2 minutes. Then add a drop of iodine to each jar. The iodine should turn the starch a deep blue. Wait a few more minutes and notice if there is any other change.

Put each of the jars into a sink containing warm water and notice if there is any change. The water in the jars containing saliva should become clear as the starch is broken down by the enzyme in the saliva.

If your results are not as good as you might like, repeat the experiment using cornstarch dissolved in water instead of the bread or cracker.

Polymers that can be used for clothing and shelter can now be made in the laboratory and factory

Synthetic Polymers

Polymers have been made in the laboratory for over 100 years. *Celluloid,* a synthetic cellulose, was made in 1868 by John Wesley Hyatt, an American. It was the only synthetic polymer until 1909. At that time Leo Hendrik Baekeland, a Belgian-born American, synthesized a woodlike material which is called *Bakelite.*

Since then, a large variety of polymers with many different forms and properties have been synthesized. Most synthetic polymers are not chemically reactive. But they differ in their resistance to weather, cold, or corrosive chemicals. Some are electrical insulators; others are heat insulators; still others muffle sound.

Some polymers can be rolled into sheets, or cast into forms. Others can be pulled into fiber that can be used in the manufacture of clothing and fabrics. There are polymers that take on a fixed shape during manufacture and cannot be changed. And there are polymers that soften when heated and stiffen again when cold.

There are probably dozens of *plastic* materials around you. You may be wearing clothing made of *nylon, rayon,* or *Orlon.* And your breakfast may have been cooked in a pan lined with *Teflon.* All of these are synthetic polymers.

The greatest advances in polymer chemistry have come in the last 15 to 20 years. Chemists have begun to understand how the structure of a polymer affects the properties of the synthetic material. Thus they learned to tailor-make materials. And the end of their discoveries is not in sight. The possibilities are apparently endless because the variety is endless. And all of these new materials begin, in effect, with coal for carbon, air for oxygen and/or nitrogen, and water for hydrogen.

Unfortunately the picture is not quite so rosy as the manufacturers of all these products would have us believe. Many of the synthetic polymers are not *biodegradable.* That is, they are not broken down in nature. Others give off poisonous chemicals as they decompose. And none can be manufactured without the dangers of pollution that seem to be a part of chemical technology.

ON YOUR OWN

Synthetics

Look around your home and list the different synthetic fibers that you find. Also list the kinds of plastics. Are there more synthetics or more natural materials in your home?

19·11

There are many serious problems that have arisen from our advances in chemical technology

The Fly in the Ointment

The chemical industry provides us with many comforts. We have replaced the horse that runs on oats with automobiles that run on chemicals from petroleum. We have substituted artificial fibers such as nylon and polyesters for natural fibers so that our clothing needs no ironing. We use plastics so we can throw them away. And we use chemical pesticides to kill insects that spread disease, destroy our fruits and vegetables, or just annoy us.

But each of these chemicals has some bad effects. One is obvious. Our environment is being damaged by wastes from products that make our lives easier. Another is not so obvious. We take into our bodies—in food, air, and water—more chemicals than ever before. And we do this without considering the effects that these may have over a long period of time.

Effects on people

Many chemicals are added to food intentionally. For instance, if you examine the print on a package of potato chips, you might find that BHT or BHA has been added. These compounds prevent the fat in the chips from spoiling by reacting with the oxygen in the air. They make it possible to keep potato chips on the shelf longer without spoiling.

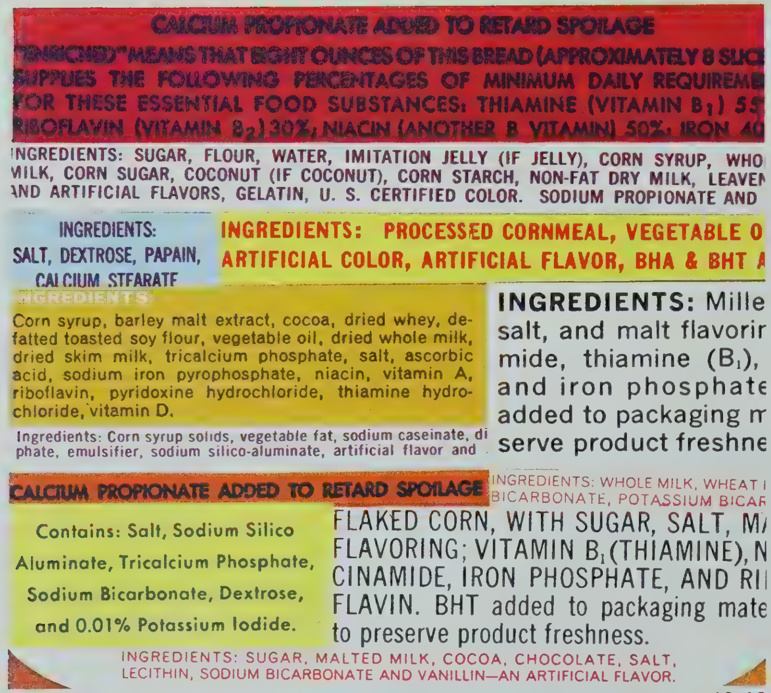
But have the BHT and BHA been tested enough to prove that they are harmless to the people who eat the potato chips? At one time, a question was raised about the safety of BHT. It caused birth and growth defects when it was fed in large quantities to rats. So it was studied further. Small amounts like those found in food are now considered safe.

A similar question has been raised about monosodium glutamate (MSG). This chemical improves the flavor of meats and vegetables by increasing the sensitivity of the taste buds on the tongue or possibly by increasing the flow of saliva.

Large amounts are used in Chinese-style cooking. These large amounts of MSG sometimes cause acute discomfort. For example, after eating a Chinese-style meal, some people suffer from a burning sensation of the skin, pressure in the temples, and severe chest pain—all of which go away in about 45 minutes. But in small amounts like those in ordinary food, no ill effects due to MSG have been reported.

What about artificial sweeteners? At one time cyclamates, about 30 times as sweet as sugar, were added to diet soft drinks and canned fruit. At present the law does not permit use of cyclamates. When fed to rats in large quantities they sometimes caused birth defects and cancer. Because no harmful effects in people have been reported, the use of cyclamates is still being debated. Even saccharin, an artificial sweetener that has been used for years, is being tested. Therefore research is being done to find other artificial sweeteners—ones with no ill effects.

Many other chemicals are unintentionally added to our foods. For instance, antibiotics are often fed to cattle and poultry. They then appear in the beef and chicken we eat. These chemicals are



CALCIUM PROPIONATE ADDED TO RETARD SPOILAGE
"ENRICHED" MEANS THAT EIGHT OUNCES OF THIS BREAD (APPROXIMATELY 8 SLIC
UPPLIES THE FOLLOWING PERCENTAGES OF MINIMUM DAILY REQUIREME
OR THESE ESSENTIAL FOOD SUBSTANCES: THIAMINE (VITAMIN B_1) 55
IBOFLAVIN (VITAMIN B_2) 30%, NIACIN (ANOTHER B VITAMIN) 50%, IRON 40

INGREDIENTS: SUGAR, FLOUR, WATER, IMITATION JELLY (IF JELLY), CORN SYRUP, WHO
MILK, CORN SUGAR, COCONUT (IF COCONUT), CORN STARCH, NON-FAT DRY MILK, LEAVEN
AND ARTIFICIAL FLAVORS, GELATIN, U. S. CERTIFIED COLOR. SODIUM PROPIONATE AND

INGREDIENTS:
SALT, DEXTROSE, PAPAIN,
CALCIUM STEARATE

INGREDIENTS: PROCESSED CORNMEAL, VEGETABLE O
ARTIFICIAL COLOR, ARTIFICIAL FLAVOR, BHA & BHT A

INGREDIENTS
Corn syrup, barley malt extract, cocoa, dried whey, defatted toasted soy flour, vegetable oil, dried whole milk, dried skim milk, tricalcium phosphate, salt, ascorbic acid, sodium iron pyrophosphate, niacin, vitamin A, riboflavin, pyridoxine hydrochloride, thiamine hydrochloride, vitamin D.

Ingredients: Corn syrup solids, vegetable fat, sodium caseinate, di
phate, emulsifier, sodium silico-aluminate, artificial flavor and

INGREDIENTS: Mille
salt, and malt flavorir
mide, thiamine (B_1),
and iron phosphate
added to packaging m
serve product freshne

CALCIUM PROPIONATE ADDED TO RETARD SPOILAGE

INGREDIENTS: WHOLE MILK, WHEAT
BICARBONATE, POTASSIUM BICAR

Contains: Salt, Sodium Silico Aluminate, Tricalcium Phosphate, Sodium Bicarbonate, Dextrose, and 0.01% Potassium Iodide.

FLAKED CORN, WITH SUGAR, SALT, M
FLAVORING; VITAMIN B_1 (THIAMINE), N
CINAMIDE, IRON PHOSPHATE, AND RI
FLAVIN. BHT added to packaging mate
to preserve product freshness.

INGREDIENTS: SUGAR, MALTED MILK, COCOA, CHOCOLATE, SALT, LECITHIN, SODIUM BICARBONATE AND VANILLIN—AN ARTIFICIAL FLAVOR.

19·13

ON YOUR OWN

Food additives

Read the labels on packaged and canned foods in the kitchen. Notice the food additives named on the labels. How many foods could you find that had *no* additives?

good for the animals, but they may do serious harm to us when we eat the meat or poultry. Some scientists fear that harmful bacteria may become resistant to the antibiotics present in food. That is, they fear that the antibiotics would no longer kill the bacteria and would thus be useless in the treatment of disease.

Heavy metal compounds also get into our foods. They are poured into lakes and streams in wastes from industrial processes. And they are not destroyed in the environment. They stay for a long time, and often are found in fish and other seafood. Mercury seems to be the heavy metal whose compounds worry people most. In large amounts (greater than those presently found in seafood) they affect the nervous system, causing muscular spasms and mental disturbances.

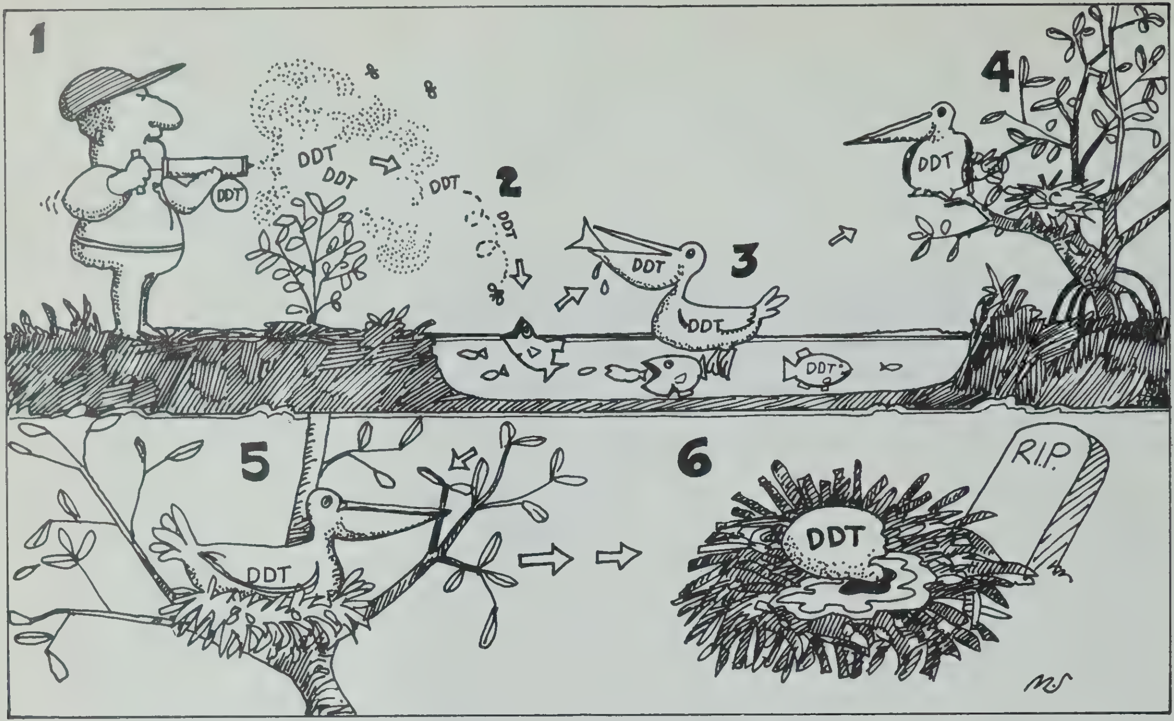
Large amounts of the heavy metal compounds poured into lakes and streams can get into our food by an indirect process. That process begins with plankton and other small water organisms. To obtain food, these small organisms filter large amounts of water through their bodies. Any heavy metal compounds in the filtered water remain in the organisms along with their food.

These small organisms are food for small fish in the lakes and streams. Each small fish eats many such organisms every day. If the organisms are contaminated, the fish will also become contaminated. The heavy metal compounds that were in the organisms will build up in the tissue of the fish.

Small fish, in turn, are eaten by larger fish. If the larger fish continue to eat contaminated small fish, more and more of the heavy metal compounds will be concentrated in their bodies. These larger fish may then be eaten by even larger ones which have eaten other contaminated fish. Eventually a fisherman could catch one of those larger fish. But let's hope it doesn't get to the dinner table.

In 1971, swordfish, which are quite large, were removed from the market because they contained too high a concentration of mercury compounds. About one half part (measured as mercury) per million parts of body weight is considered safe.

Fish and seafood (as well as poultry and beef) also contain pesticides, notably DDT that has been sprayed over forests and fields. These compounds become concentrated in the foods we eat, much in the same way as the heavy metal compounds become concentrated in fish. Grazing cattle eat DDT sprayed on the field, along with the grass. DDT is deposited in the fat of humans and animals. In one study of 800 Americans, an average of 12 parts per million was found in their body fat. But in New Delhi, India, where much DDT has been sprayed to control malaria-causing mosquitoes, an average of 26 parts per million has been found. So far, however, no illnesses recognized as caused by pesticides in food have been reported.



19·14 (1) The gardener sprays DDT around the bush, killing the bugs. (2) A bug falls into the inlet where it is eaten by a fish. (3) The fish is eaten by a water bird. (4) The bird builds a nest near the inlet and eats other fish that contain DDT. (5) The bird lays an egg. (6) The egg shell does not contain enough calcium and breaks before a baby bird can develop.

Effects on environment

The build-up of pesticides and other chemicals in lakes and streams is disturbing the natural balance in the environment. Birds of prey, especially those that feed on fish, have suffered. In some way, DDT and similar pesticides seem to change the body chemistry of these birds so that less calcium is in their eggshells. This causes the shells to be thin and break before young birds can be hatched. In parts of southern California where large amounts of DDT have been sprayed on farmlands, brown pelicans and double-crested cormorants (a kind of sea bird) are unable to reproduce.

Industry adds to the disturbance of the balance in nature. Each type of chemical industry adds its own kind of pollution to lakes and streams. One paper mill can discharge as much as 14 tons of solid material each day. One steel mill can pour out organic matter in one day equal to the sewage from a city of 300,000 people. And oil refineries, too, pour out organic wastes into our streams and rivers.

Discharge of such wastes plus sewage from cities kill fish and make waters unsuitable for recreation. But another serious problem is involved. Aging of lakes, a process called *eutrophication,* is speeded up. Phosphorus in detergents and nitrogen from fertilizers and human wastes are accused of helping to do this.

19·15 A water bird swimming through an oil spill.

Lakes age naturally because organic matter and mud are washed into them by streams. As the organic matter decays, it reacts with oxygen and also supplies nutrients for algae, which are very hardy plants that grow in water. Then as the algae continue to grow, die, and decay, they react with more oxygen. Fish and other animals that live in the water die from lack of oxygen and they, too, decay. Eventually the lake is filled with mud and other material and becomes a swamp. Thousands of years are required for this process to occur naturally. Lake Erie, which is highly polluted, is said to have aged as much in the last 50 years as it would have naturally in 15,000 years.

Ocean waters, too, are affected by pollution. Here, oil spills are a main offender. In 1970, Thor Heyerdahl, a Norwegian explorer, reported that he saw in mid-ocean a 1,400-mile stretch of water where thousands of lumps of asphalt-like oil floated. These lumps remain after the rest of the petroleum has evaporated.

Oil spills also smear our ocean beaches. Many birds are killed because their feathers become oil-soaked and they cannot fly. In a single accident, as many as 200,000 were killed when the *Torrey Canyon* ran aground off the coast of England in 1967. It spilled about 120,000 tons of oil.

Our air contains chemicals from pollution, too. Burning of gasoline, coal, and oil releases carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides, hydrocarbons, and carbon particles seen as dark smoke.

19·16 Sydney, Australia, also has smog.

In the presence of sunlight, these chemicals react with each other to cause smog. Then if an air inversion takes place (a layer of cool air forming a lid over warm air near the ground) a phenomenon called synergism can cause a disaster. In this case synergism means that the effects of two pollutants in contact with each other can be more harmful than the sum of the effects of each alone.

Another kind of smog is produced when bright sunlight causes nitrogen oxides and hydrocarbons to react. They form products which then react with oxygen to form ozone (O_3), a chemical that is very irritating to the nose and throat. This type of smog, called photochemical smog, also contains another irritating chemical, labeled PAN. It is also formed by a reaction of nitrogen oxide and a hydrocarbon.

In addition to smog-forming chemicals, automobile exhaust contains volatile lead compounds. Each gallon of leaded gasoline contains about 2 grams of lead in the form of tetraethyl lead or tetramethyl lead. These chemicals make the car run more quietly, and, as gasoline is burned, the lead it contains is discharged to the air. People breathe the lead and absorb it through their lungs. Lead is poisonous. And it is not yet known how it is affecting people who live in the downtown sections of cities or alongside heavily traveled highways in some large cities.

Encouraging trends

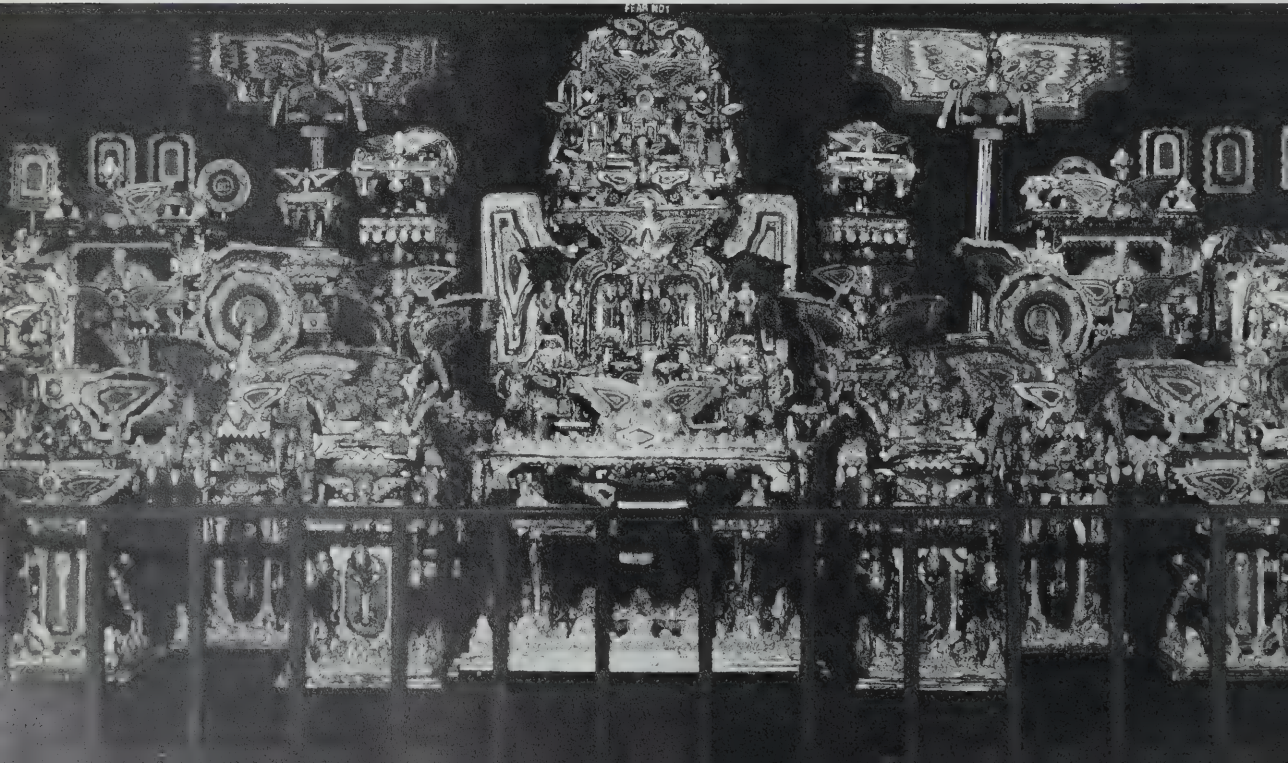
An obvious way to reduce lead in our air is to use gasolines without lead. Some are already on the market and more are on the way. But a complete changeover would be very expensive. Other suggested solutions include improved public transportation systems, outlawing the use of private automobiles in the center city, the use of bicycles for transportation over short distances, more walking, and improvement or replacement of the internal combustion engine.

Trends in other kinds of pollution control are encouraging, too. People are beginning to realize that their planet, Earth, is not a huge garbage can. Some are even wondering if we need all the conveniences we have. For instance, do we need throwaway beverage cans and bottles?

19·17 Students cleaning up a polluted area.

Chemists also are aware of pollution. They are searching for methods of solving pollution problems caused by the growth of their industry and by population increases. And the chemical industry as a whole has become pollution-conscious. It has reduced sharply the amount of mercury reaching lakes and streams and has developed processes for removing sulfur oxides and carbon particles from smoke.

Substitutes for phosphates in detergents are being tested. Two methods of cleaning oil spills show promise. Most promising of all is that the United States government is taking action. It has established a large agency, the Environmental Protection Agency, to protect the environment. It is up to the citizens of the United States to see that this agency performs the job for which it was established.



19·18 Throne of the Third Heaven of the National Millennium General Assembly by James Hampton. This work is made of discarded objects covered with aluminum foil.

A thought and discussion question

The Good Old Way

Our present way of life is very costly in terms of damage to the natural environment. Many people are looking for ways to reduce this cost. They feel that we are ruining an environment which is necessary for our survival.

Some students of the environment have suggested that all of our problems are due to the spread of technology. One noted biologist has suggested that we return to a simpler way of life—one in which we discard many of the products of modern technology.

Since most modern technology is indeed chemical technology, this might be a good place to think about that biologist's suggestions. Let's look at a few of the changes that have taken place in the United States over a span of 100 years.

In 1870 the United States was an agricultural nation with a population of about 38.5 million. Almost 75 percent of those people lived in rural areas. In 1970 the United States was an industrial nation with a population of over 203 million. And 65 percent of the people lived in the large metropolitan areas that surround our cities.

The change from agricultural to industrial nation has been most obvious down on the farm. For instance, the farmers of 1870 used a plow, cultivator, reaper, scythe, and hoe to farm their land. They built their own farm buildings and fences out of the wood they cut down to clear the land. And they raised the horses and mules with which they worked the land.

Farming stayed about the same until 1920. But the number of acres being farmed rose steadily. The average yields per acre were about the same as they had been in the early 1800's.

Mechanization hit the farms in the late 1920's with the invention of the general-purpose tractor. That was followed by the introduction of corn hybrids that increased corn yields by 20 to 25 percent. The number of work-hours spent in farming fell from 23 billion in 1930 to 15 billion by 1950.

But there was really very little change in farming practices until 1950. Crops were rotated on a three-year schedule—corn, oats, clover, and back to corn. The corn was planted *without* fertilizer in 40-inch rows. It was necessary to plant 10,000 seeds on an acre of land to yield 38 bushels of corn.

19·19 Crop being sprayed from an airplane.

Chemical technology took over the farm just after World War II. New fertilizers were developed. Herbicides, compounds that would kill the weeds and leave the crops unharmed, were discovered. The insecticides used to protect our military people from insect-borne diseases in the tropics were modified. So many farms were mechanized that the Agricultural Census stopped counting horses and mules. The farm was now a part of the age of technology.

Today corn crops are seldom rotated. Instead, 150 pounds of nitrogen fertilizer are applied to each acre of soil. Then 25,000 seeds are planted in 20-inch rows. Weeds are controlled by spraying the fields with herbicides. And insects are eliminated by spraying the fields with insecticides.

The average yield is now 90 to 100 bushels an acre. The farmer who used to plant 35 out of each 100 acres to get 1250 bushels of corn in 1950, now plants the entire 100 acres and gets 9000 to 10,000 bushels of corn!

The same sort of thing has happened to the other farm crops. The yield of wheat has doubled since 1930, and new hybrids promise another 25 percent rise. And the yield of cotton has tripled.

A good part of the damage to the natural environment is caused by the nitrogen fertilizers, the herbicides, and the insecticides used by modern farmers. It is thus very tempting to suggest that the use of these chemicals be outlawed. If this were to happen, farmers would have to return to the farming methods of the late 1930's.

The yields of their crops would also return to those of the 1930's, although hybrid seeds that have been developed since then might raise the yields somewhat.

In the late 1930's the United States had a population of about 130 million. Though the farmers of that time had to feed only two-thirds as many people, they had to plant more acres of each crop. Their yields per acre were smaller.

Today, if farmers were to plant the same number of acres, using the best hybrid seeds without modern chemical methods, they would harvest 12 percent less corn and 25 percent less wheat than they now do. The yields of all other crops, from fruits and vegetables to cotton and flax, would also drop.

If the use of fertilizers, herbicides, and insecticides were outlawed, how would you be affected? What would happen to the food for sale at the local grocery? Would the United States still have enough food to export to other parts of the world? Would we have to import food in large quantities? If so, would the food be available for import? And would we be able to import it?

How might the return to old farming methods affect what you wear? In what ways could it affect your life style? your place of residence? your family's source of income?

Would a return to the old methods of farming improve the environment of the United States? Do you think this is an acceptable solution to our problems of environmental pollution? If it is not acceptable, what alternatives can you suggest? Think about it.

If you would like to read more about this subject, look up the following topics in *The Readers' Guide to Periodical Literature*, in your library card catalog, or in an encyclopedia:

- **agriculture**
- **clover**
- **corn**
- **crop rotation**
- **farm, equipment**
  - **mechanization of**
  - **modern**
  - **nineteenth century**
- **fertilizers**
- **herbicides**
- **hybrids**
- **insecticides**
- **oats**
- **population growth**
- **tractors**

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Appendix B: page 516

Appendix C: page 531

Appendix A: *The Metric System*

Our system of weights and measures goes back thousands of years. It mirrors the variety of measurements used over that time. So our system has *many* terms, some of which have more than one value.

An inch was 3 barleycorns laid end to end, *or* the length of a thumb joint. A foot was the length of a soldier's boot, with about 12 inches to a foot. A cubit was the length of the arm from elbow to fingertip. And two cubits was a yard or about 3 feet.

A mile was 1000 paces of 2 steps, or 5000 feet, before it became 5280 feet, or 1760 yards.

One grain was a grain of wheat. One pound was 7000 grains. Quite a few units to memorize!

The Metric System of Weights and Measures was developed about 200 years ago. It is now the international standard for weights and measures used by most people in the world.

In fact, the U.S. is the last big nation not using metric units in everyday life. But the situation is changing. The next time you are at the grocery store, notice the number of items labeled in both ounces and grams.

Have a new bike? Many of the parts are probably in metric units. And what about all those American cars sold overseas? Every last measurement is metric. There is little doubt that within your lifetime everyone in the U.S. will need to "think metric."

The metric system is easy to use. It is based on the unit of 10. And you need to remember only two main things:

(1) There are three basic terms: *meter* for length, *liter* for volume, and *gram* for mass.
(2) The prefixes used with each basic term tell you where to put the decimal point.

Chart I			
Prefixes and their values:			
kilo	(kil′ ə)	1,000	
hecto	(hek′ tə)	100	
deka	(dek′ ə)	10	
basic terms: gram = 1; meter = 1; liter = 1			
deci	(des′ ə)	1/10 or 0.1	$\overset{.1}{(10\overline{)1.00})}$
centi	(sen′ tə)	1/100 or 0.01	$\overset{.01}{(100\overline{)1.00})}$
milli	(mil′ ə)	1/1000 or 0.001	$\overset{.001}{(1000\overline{)1.000})}$

You can use the data in CHART I in the following way: Find the word "meter." Remember that the meter is the basic metric unit of length. It is given the value of 1. A *kilo*meter is 1000 times greater in value than a meter. A *deci*meter would be 1/10 the size of a meter. A *centi*meter would be 1/100 the size of a meter. And a *milli*meter would be 1/1000 the size of a meter.

Therefore, if a distance is one kilometer, you know that it is 1000 meters (10 × 10 × 10), or 100,000 centimeters (10 × 10 × 10 × 10 × 10), or 1,000,000 millimeters (10 × 10 × 10 × 10 × 10 × 10).

If you have 53 centimeters, you know that you have 10 × 53 or 530 millimeters, and 0.01 × 53 or 0.53 meters.

Enough on meters. When you use grams in the metric system, it is important to remember you are talking about something's *mass.* The mass of an object is different from what is meant by an object's weight. For example, think of *mass* as a mule.

The mule is a stubborn animal and often resists a person's attempts to make it move. To overcome the mule's resistance, it is necessary to pull hard. In this respect all objects act like a mule. When they are at rest, they resist attempts to make them move. When they are moving, they resist attempts to speed them up, slow them down, or make them turn.

The "stubbornness" of an object to resist any change in motion is called its *mass.* The more *mass* an object has, the harder you have to push it or pull it to change its motion.

Weight is closely related to *mass. Weight* is a measure of the pull of gravity on the *mass* of an object. Since the pull of gravity changes from place to place, the *weight* of an object changes from place to place. But, the *mass* would remain the same.

However, the differences in the pull of gravity over earth's surface are too small to worry about. So, we often equate *mass* (grams—kilograms) with *weight* (ounces—pounds) in everyday use.

In science, the difference between what is meant by an object's *mass* and its *weight* is important. In this program, an object's *mass* will be expressed in *grams* and *kilograms.*

(Note: There will be more on mass and weight in the Motion Unit.)

That brings us to liters. A liter is the basic metric measure of volume—or the space something takes up. In this program, volumes are measured in 1/1000's of a liter, or *milliliters.*

The milliliter is the metric unit which is used to show how length, mass, and volume units are related to each other in the metric system. For example, 1 milliliter of a liquid will fill a cube that is 1 centimeter long in each direction. Or 1 milliliter is equal to 1 *cubic centimeter.* If that milliliter is a cubic centimeter of water at 4°Celsius, it will have a mass of 1 gram.

CHART II will help you make changes from one system to another. CHART III will help you with abbreviations used in your lab work and readings.

Practice Problems in Using the Metric System

1. A can of peaches from the store has a mass of 543 grams. How many kilograms is it? How many milligrams is it? How many pounds is it?

2. A liter is defined as one cubic decimeter (or the volume of a box one decimeter on each side). How many cubic centimeters are in one cubic decimeter? If 1 cubic centimeter of water equals 1 gram, how much mass does one liter of water have?

3. Every four years we have an opportunity to watch the Olympic Games on television. The events that the athletes compete in are measured in metric distances. Figure out the distances in yards and feet for the following events: 100-meter backstroke, 400-meter hurdles, 1000-meter speed skating, and a 20,000-meter race.

4. Potatoes are often sold in 10-pound sacks. How many kilograms of potatoes is this?

5. One well-known German car takes 10.6 gallons of gas and 5.3 pints of oil. These volumes are sometimes difficult for us to use because they are not whole numbers. However, Germany is a metric country. How many liters are in 10.6 gallons? How many liters are in 5.3 pints?

Chart II

Approximate conversions from U.S. to metric and vice versa.

	WHEN YOU KNOW:	YOU CAN FIND:	IF YOU MULTIPLY BY:
LENGTH	inches	millimeters	25
	feet	centimeters	30
	yards	meters	0.9
	miles	kilometers	1.6
	millimeters	inches	0.04
	centimeters	inches	0.4
	meters	yards	1.1
	kilometers	miles	0.6
MASS	ounces	grams	28
	pounds	kilograms	0.45
	grams	ounces	0.035
	kilograms	pounds	2.2
LIQUID VOLUME	ounces	milliliters	30
	pints	liters	0.47
	quarts	liters	0.95
	gallons	liters	3.8
	milliliters	ounces	0.034
	liters	pints	2.1
	liters	quarts	1.06
	liters	gallons	0.26

Dodge News Magazine: Chrysler Motors Corp.

Chart III

Abbreviations for units most often used in this program:

meter	(m)	kilometer	(km)
centimeter	(cm)	kilogram	(kg)
millimeter	(mm)	milliliter	(ml)

cubic centimeter (cc)

Light Unit

TEST YOURSELF (p. 10)

1. *Red, orange, yellow, green, blue, indigo, and violet.*
2. *A prism and a diffraction grating.*
3.

filter	spectrum colors passed through	major color areas blocked
red	*red*	*blue and green*
green	*green*	*red and blue*
blue	*blue*	*red and green*
yellow	*red, green, yellow*	*blue*
cyan	*blue and green*	*red*
magenta	*blue and red*	*green*

4. *(a) Red and yellow filters will pass RED.*
   (b) Cyan and green filters will pass GREEN.
   (c) Blue and yellow filters will pass NONE. (Blue blocks those spectrum colors the yellow filter doesn't block; the result is no color passes.)
   (d) Blue and green filters will pass NONE.
   (e) Magenta and red filters will pass RED.
   (f) Magenta and yellow filters will pass RED. (Note in figure 1·1 that magenta does not pass the spectrum color yellow.)

5. *Using the table from question 3 or figure 1·2, you can see that the two filters in combination that block all the colors of the spectrum are (a) blue and green, (b) red and blue, and (c) red and green.*

TEST YOURSELF (p. 15)

1. *The yellow reflects the red and green parts of the spectrum. Since only* red *is available to be reflected, that's what you see.*
2. *Green. The pure green opaque surface reflects only the green part of the spectrum. Since only green is available to be reflected, that's what you see. All the light received by the plant, which is green only, is reflected back. Therefore, none is absorbed to be used to manufacture chlorophyll.*
3. *Yellow paint reflects red and green light and absorbs blue. Cyan paint reflects blue and green light and absorbs red. Therefore, a mixture of the two would reflect only green in white light.*
4. *Magenta (red-blue) reflects red and blue and* absorbs green. *Cyan (blue-green) reflects blue and green and* absorbs red. *The blue light will be reflected.*

TEST YOURSELF (p. 23)

1. *(a) When a pure green beam overlaps a pure blue beam of light on a white surface, you see cyan (blue-green).*
   (b) When a pure green beam overlaps a pure red beam on a white surface, you see yellow.
   (c) When a pure blue beam overlaps a pure red beam on a white surface, you see magenta (red-blue).
2. *A white area.*
3. *A pure red beam mixed with a pure blue beam produces magenta. A blue opaque surface reflects blue light and absorbs red light. Only the blue light in the magenta beam is reflected. You would see blue.*

TEST YOURSELF (p. 35)

1. *In all directions. You can see him or her from any part of the room.*

2. *Normal is the line drawn perpendicular to the surface of a mirror. This line is drawn at a point where a ray of light hits the mirror. It is used to compare the angle of incidence with the angle of reflection.*

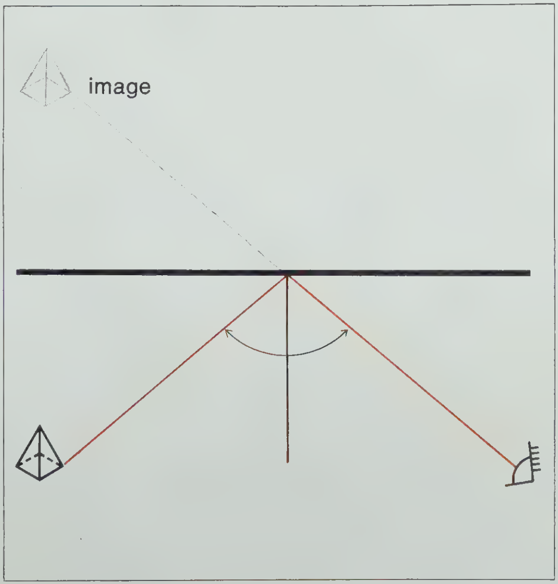
3. (a) *Green is 50°; red is 60°. (b) They are equal.*

TEST YOURSELF (p. 40)

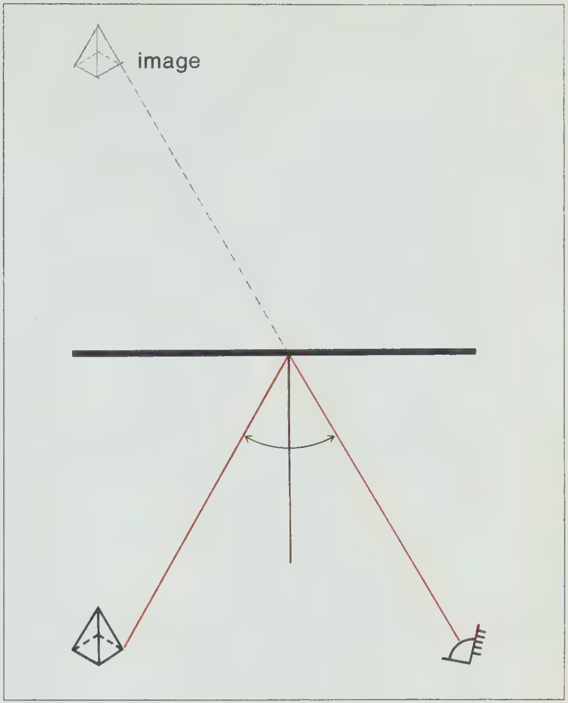
1. *No. You can't twist your hands that way. The reflection of your left hand in a flat mirror looks just like your right hand.*

2. (a) *It will always appear the same size because a flat mirror does not magnify or reduce the size of a virtual image.*
   (b) *It will appear to be an equal distance inside the mirror as the object is in front of it.*
   (c) *No. If you could stand where your image is in a mirror, the image's right hand is directly opposite your own real left hand. You are facing your image. Such an image of yourself is possible to see in a flat mirror because of the law of reflection.*

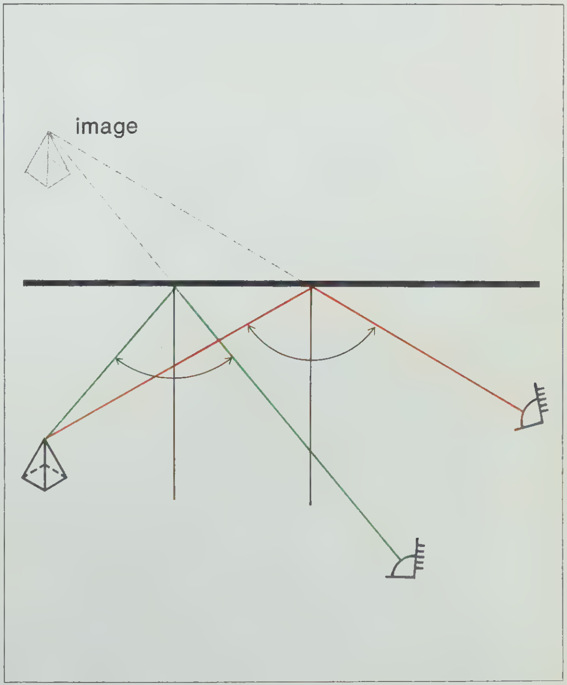
3.



2·14



2·15



2·16

TEST YOURSELF (p. 46)

1. *An inwardly curved surface is called* concave.
2. *The three kinds of images you can see in a concave mirror are:*
   (a) A larger than life-size image of your face, right-side-up, when you are close to the mirror.
   (b) A blur of color when you are farther away.
   (c) An up-side down image of your face when you are even farther away.
3. *Yes. It works as if a concave mirror were made up of many small flat mirrors in a curved line.*
4. *Light beams parallel to the center line of a mirror, after striking the concave surface of that mirror, are reflected back and cross at a certain distance in front of the mirror. The point where the parallel rays cross is called the* focal point.
5. *The distance from the* center *of a curved mirror to its focal point is called the* focal length.
6. *Light beams shining through a focal point toward the concave mirror surface will be reflected and travel parallel to the center line of the mirror.*

TEST YOURSELF (p. 49)

1. *A real image (upside-down image).*
2. *A virtual image and larger than life-size.*
3. *The object will appear blurred if it is* exactly *one focal length from the center of the concave mirror.*
4. *(a) Light rays striking a mirror parallel to the center line of the mirror will be reflected and meet at the focal point of a concave mirror.*
   (b) Light rays that pass through the focal point before hitting the concave mirror will be reflected parallel to the center line of the mirror.
5. *(a) If the object is placed between one and two focal lengths in front of a concave mirror—its real image is larger than life size, is upside down, and is located over two focal lengths from the mirror.*
   (b) If the object is placed at two focal lengths in front of a concave mirror—its real image is still upside-down but its size is life-size and it is located also at two focal lengths.
   (c) If the object is placed at a distance a little farther than two focal lengths from a concave mirror—its real image gets smaller than it was at one focal length and is still upside-down. The image is now between one and two focal lengths from the mirror.
   (d) If the object is noticeably farther than two focal lengths from the concave mirror, the image will be very *small, upside-down, and about one focal length from the mirror.*

TEST YOURSELF (p. 57)

1. *Larger . . . . if the image is at the same distance as it was originally.*
2. *Smaller . . . . if the object remains at the original distance from the pinhole.*
3. *Less bright . . . . less light on more area.*
4. *It changes the size and sharpness of the image. If the hole is larger, the size of the image becomes larger and blurred.*
5. $$\frac{\textit{height of image}}{\textit{distance from pinhole}} = \frac{\textit{height of house}}{\textit{distance from pinhole}}$$

   $\frac{1}{3} = \frac{?}{36}$ $3? = 36$ *House is* 12 meters tall.

TEST YOURSELF (p. 71)

1. *Angle of incidence is the angle between the incident (entering) ray of light and the normal. Angle of refraction is the angle between refracted (bent) ray of light and the normal.*

   (a) Your diagram should look like the one in figure 4·1 where a narrow light beam enters a glass block. The light beam is not bent.
   (b) The angle of incidence should appear to be a little farther from the normal than the angle of incidence seen in figure 4·2. The line you drew to show the light has been refracted should appear to be a little farther from the normal than what you see in figure 4·2.

3. Light enters each of these substances at a 45° angle, so your diagram should show:
   (a) The glass block (index of refraction = 1.53) bends light toward the normal.
   (b) The quartz block (index of refraction = 1.46) bends light toward the normal but less than the glass block.
   (c) The box of water (index of refraction = 1.33) bends light toward the normal but less than the quartz block and the glass block.

4. Your diagram should show the light bending sharply toward the normal, as it goes from the air (index of refraction = 1) into the glass (1.53). Then as the light beam travels from glass (1.53) into the quartz (1.46), it should bend slightly away from the normal. Then as the light beam goes from the quartz (1.46) into the water (1.33), it should also bend slightly away from the normal. Note that as light travels from a substance with a low index of refraction to one with a high index of refraction, it is bent toward the normal. As light travels from a substance with a high index of refraction to one with a lower index of refraction, it is bent away from the normal.

TEST YOURSELF (p. 79)

1. A double-convex lens has both sides curving out. Such lenses are often used for magnifying glasses and cameras.

2. A double-convex lens brings beams, which strike its surface parallel to each other, together at the focal point.

3. Two—one on either side of the lens. Light can pass through the lens from either side.

4. Light beams that go through the exact center of the double-convex lens, at any angle, are not bent.

TEST YOURSELF (p. 84)

1. Real

2. Virtual

3. The real image formed by a double-convex lens is upside-down and reversed. The virtual image formed is right-side-up and not reversed. You can only catch a real image on a card.

4. (a) Object very far from lens: a small, upside-down, real image at the focal point behind the lens.
   (b) Object two focal lengths from lens: life-size real image, upside-down, reversed, at two focal lengths behind the lens.
   (c) Object between one and two focal lengths from lens: real image larger, upside-down, reversed, at more than two focal lengths behind the lens.
   (d) Object less than one focal length from lens: larger than life-size, virtual image, at more than two focal lengths in front of the lens.

5. (a) Compare your answer with figure 4•17, page 81.
   (b) Compare your answer with figure 4•18, page 81.
   (c) Compare your answer with figure 4•19, page 81.
   (d) Compare your answer with figure 4•21, page 82.

TEST YOURSELF (p. 99)

1. The flash from a camera light bulb is intense close up. It's too weak to light up an object at any great distance.

2. Smaller. The light intensity gets less as distance from the light source increases.

3. If distance is doubled, intensity drops by a factor of 4. (48 divided by 4 = 12 is the intensity reading.)

4. At 60 cm from the light source, you are three times as far as you would be at 20 cm. (Use table 2.) Intensity at near point, x, is to intensity at far point, 20, as (distance to far point)^2, $(60)^2$, is to (distance to near point)^2, $(20)^2$.

   X is to 20 as 3600 is to 400
   X is to 20 as 36 is to 4
   X is to 20 as 9 is to 1
   180 is to 20 as 9 is to 1

   Note that for each three-fold increase in distance, the intensity drops by a factor of nine. The reverse is also true. At 60 cm the meter reads 20 intensity units. At 20 cm the meter reads 180 intensity units.

Electricity

TEST YOURSELF (p. 129)

1. (a) An amp is the unit of measure for the number of coulombs streaming through a wire each second. (1 amp is equal to 1 coulomb per second.)
   (b) Electrical energy per coulomb is measured in units called volts.

2. A circuit is the complete path of electricity as it flows from the source, through an electricity user, and back again. Materials which easily carry the electricity in a circuit are called conductors. Materials which do not conduct much electricity are called insulators. By acting as barriers to the flow of electricity, insulators help direct the flow of current.

3. An ammeter is connected so that all the current in the circuit passes through it. A voltmeter is connected with one terminal on each side of a user of electrical energy. Only a small part of the current passes through a voltmeter.

4. The three devices will divide the total energy supplied by the battery. You can find the total amount of energy supplied by the battery by adding the amounts used by each device. The voltmeter at each device will show how much that device is using.

5. Originally the dump truck carried 24 units of energy (volts) to bulb #1, and 9 units of energy (volts) to bulb #2. If the positions are reversed, the truck would be carrying 24 units to new bulb #1, and 21 units to bulb #2.

TEST YOURSELF (p. 138)

1. The unit for electrical energy per second is the watt (amps × volts = watts).

2. 5 amps × 120 volts = 600 watts (electrical energy per second).

3. 1000 watts are in 1 kilowatt.

4. 3 hours × 7 days = 21 hours, 100 watts × 21 hours = 2100 watt-hours or 2.1 kilowatt-hours (used in 7 days).

TEST YOURSELF (p. 141)

1. Divide the total number of volts by amps to find the electrical resistance of a circuit.

   $$\text{ohms} = \frac{\text{volts}}{\text{amps}}$$

2. $\frac{120 \text{ volts}}{10 \text{ amps}} = 12 \text{ ohms}$ (resistance of hot plate)

3. The total amount of energy supplied is 9 volts × 2 = 18 volts. (?) amps × 18 volts = 36 watts
   amps = 2

   $\frac{18 \text{ volts}}{2 \text{ amps}} = 9 \text{ ohms}$ (resistance of phonograph)

4. An appliance with high resistance uses less wattage than an appliance with low resistance because it allows less current (amps) to pass through over a certain period of time.

5. (a) The resistance in ohms of each bulb was different. So only a certain amount of energy was allowed to pass through each bulb and be used.

   (b) $\frac{\text{volts}}{\text{amps}} = \text{ohms}$

   Figure 6•12: $\frac{15 \text{ volts}}{2 \text{ amps}} = 7.5 \text{ ohms};$

   $\frac{3 \text{ volts}}{2 \text{ amps}} = 1.5 \text{ ohms}; \frac{6 \text{ volts}}{2 \text{ amps}} = 3.0 \text{ ohms}.$

   Figure 6•11: $\frac{7.5 \text{ volts}}{2 \text{ amps}} = 3.75 \text{ ohms};$

   $\frac{1.5 \text{ volts}}{2 \text{ amps}} = 0.75 \text{ ohms}; \frac{3 \text{ volts}}{2 \text{ amps}} = 1.5 \text{ ohms}.$

TEST YOURSELF (p. 147)

1. In a series circuit, each coulomb of current goes through every part of the circuit. So the amperage is the same in all parts of the circuit. In a parallel circuit, the greatest number of amps takes the path of least resistance in ohms. In a parallel circuit, each user of electricity is on a separate path.

2. The amount of amps that pass through the house wires (a parallel circuit) to the plug increases if all appliances are being used at the same time. Excess amperage can overheat the wires and cause a fire.

3. *If the amperage through a circuit is greater than the fuse can carry, the wire in the fuse melts and the circuit is broken. The circuit breaker is an automatic switch. When the amperage goes beyond a certain level, a magnet in the switch pulls the contacts apart.*

4. *The house wiring can get so hot it causes a fire. The penny allows more amperage through than should safely be carried.*

5. *No. The batteries wired in series will supply 18 volts to the radio. The batteries wired in parallel will supply only 9 volts. But in parallel, they will supply electrical energy over a longer period of time.*

TEST YOURSELF *(p. 159)*

1. *A magnetic compass is really a type of bar magnet. It is set up so that it can rotate freely. For this reason it always lines up in the north-south direction of the closest and strongest magnetic field.*

2. *The south-pointing part of a compass needle, which normally lines up in a north-south position with the magnetic field of earth, will be attracted by the N-pole of a bar magnet.*

3. *North*

4. *They move away from each other. That is, they are repelled.*

5. *The compass needle moves away from or toward the wire. A current-carrying wire has a magnetic field which affects the compass needle.*

6. *It moves according to the direction of the magnetic field in the center of the loop.*

7. *It changes the direction the compass needle moves.*

TEST YOURSELF *(p. 171)*

1. *(a) Reverse the direction of the current through the coil.*
   (b) Change the direction in which the coil is wound.

2. *If no current is traveling through the coil, the coil will have no magnetic field.*

3. *You can place a compass at one end of the coil and notice the direction in which its N-pole points. Or you can use the left-hand rule. Locate where the electricity enters the coil. Put your left hand over the coil with your fingers pointing in the direction the current is moving. When your thumb is held out straight, it will point to the N-pole of the electromagnet.*

4. *(a) Increase the number of coils.*
   (b) Use a thicker iron core.
   (c) Increase the amount of current (amps) flowing through the coils.

5. *One with 50 coils and an iron core.*

6. *One with 50 coils and an 8-amp current.*

7. *An electric current is produced in the coil of wire, but* only *while the magnet is moving.*

TEST YOURSELF *(p. 192)*

1. *An electromagnet mounted on a pivot between two permanent magnetic poles and held by a spring can be used as a meter. The electromagnet moves a certain distance, depending on the amount of current flowing through the circuit. A pointer attached to the electromagnet shows the distance moved on a scale.*

2. *The current flows through the* armature *making it an electromagnet. At each side of this electromagnet (armature) is a non-moving magnet. Each of these magnets attracts and repels poles of the armature, keeping it in motion. Meanwhile the* split-ring commutator *acts as a reversing switch. It reverses the direction of the current. So the armature keeps rotating in one direction. The* brushes *bring current from the source (battery) to the split-ring commutator. The source of current (battery) supplies the energy. All parts must work together for the motor to turn.*

TEST YOURSELF (p. 195)

1. *Horsepower is a unit for measuring the rate at which a motor uses energy. Horsepower is similar in meaning to* watts.
2. *Rotate the electromagnet (armature) in the motor by hand while the brushes are attached to an ammeter instead of a battery. As the armature rotates in the magnetic field, the field strength within the armature should change. The faster the coil is rotated, the greater will be the change and the more electricity generated.*
3. *The amount of power put out by the generator will increase.*

Motion

TEST YOURSELF (p. 224)

1. *(a) The way it starts moving, the way it goes, and the way it stops. Or whoosh (speed) and thud (start and stop).*
   (b) The speed of an object equals the distance it moved divided by the time it took.
2. $\text{Speed} = \frac{\text{distance traveled}}{\text{time interval}}$
   $= \frac{2\ \text{km}}{0.5\ \text{hr}}$
   $= 4$ km/hr *(This is her average speed. It is also her speed at 3:15 since she was walking at an unchanging rate.)*
3. $\text{Speed} = \frac{\text{distance traveled}}{\text{time interval}} = \frac{2\ \text{km}}{1.5\ \text{hr}} =$
   1.33 km/hr

TEST YOURSELF (p. 230)

1. *The mass of an object does not change. Weight is a measure of the pull of gravity on an object. Weight changes according to the size of the object attracting another object, and according to the distance between the objects.*
2. *(a) Lift both balls and relate which one seems to have a greater strain on your arms. (b) Try to stop both balls when they are moving at the same speed.*
3. *(a) Two red wagons: Both methods could be used, but the strain method would be safer and easier. Two people could stand at the top of a slightly sloping hill and let go of both wagons at the same time. Both wagons would come down together at the same speed. Stopping them might be unsafe. Trying to lift both wagons would give you an idea of the strain on each arm.*
   (b) Two sacks of mail: The strain method would be easier to use. Both sacks of mail would be lifted and the strain on each arm compared.
   (c) Two grand pianos on wheels: The thud method would be easier. You could compare how hard it is to start each one moving.
   (d) Two small children on roller skates: The thud method might be easier. Both skaters start at the top of a small rise in the sidewalk and glide down at the same speed. You could compare how hard it is to stop them.
4. *One gram is the mass of one cubic centimeter of water at a temperature of 4° Celsius.*
5. *One kilogram is a thousand-gram mass. It has become the international standard mass.*
6. *It is more convenient to measure the following in these units: (a) A pencil in* grams, *(b) yourself in* kilograms, *(c) a glass of water in* grams, *and (d) a tank of water in* kilograms.

TEST YOURSELF (p. 251)

1. *The momentum of an object is its mass multiplied by its speed. Mass × speed = momentum.*
2. *In an ideal situation,* no *momentum is lost or gained. When the mass-times-the-speed of two objects involved is added, the results show no loss or gain in momentum.*
3. *Assume ideal conditions: mass × speed = momentum.*
   $2400\ \text{kg} \times 50\ \text{km/hr} = 120{,}000\ \text{kg}\cdot\text{km/hr}$
   $2400\ \text{kg} \times 60\ \text{km/hr} = 144{,}000\ \text{kg}\cdot\text{km/hr}$
4. *Conservation of momentum is taking place. So the speed of the second ball is 17 m/sec after collision. Both balls have the same mass.*

5. *Total momentum before collision*

$$\begin{array}{lrl} \text{Cart A} & 2\,kg \times 0\ m/sec = & 0\ kg \cdot m/sec \\ \text{Cart B} & 3\,kg \times 3\ m/sec = & \underline{9\ kg \cdot m/sec} \\ & & 9\ kg \cdot m/sec \end{array}$$

Total momentum after collision

$$\begin{array}{lrl} \text{Cart A} & 2\,kg \times 4\ m/sec = & 8\ kg \cdot m/sec \\ \text{Cart B} & 3\,kg \times ?\ m/sec = & \underline{?\ kg \cdot m/sec} \\ & & 9\ kg \cdot m/sec \end{array}$$

$$?\ kg \cdot m/sec = 1\ kg \cdot m/sec$$

(momentum of Cart B after collision)

$$3\,kg \times ?\ m/sec = 1\ kg \cdot m/sec$$

$$?\ m/sec = \frac{1\ kg \cdot m/sec}{3\ kg}$$

$$?\ m/sec = 1/3\ m/sec$$

Speed of cart B after collision is 1/3 m/sec.

TEST YOURSELF *(p. 257)*

1. *Force is the push or pull needed to start something moving, to change its speed or direction while it is moving, or to stop something in motion.*
2. *The three factors are (a) the mass of the object, (b) how much of a change in speed is desired, and (c) the amount of time available to reach that certain speed.*
3. $$\text{Force} = \frac{\text{mass} \times \text{change in speed}}{\text{time interval}}$$

TEST YOURSELF *(p. 259)*

1. *(a) A force due to the engine is acting.*
   (b) The force of gravity is acting.
   (c) The force of gravity is acting.
2. $$\text{Force} = \frac{\text{mass} \times \text{change in speed}}{\text{time interval}}$$
   $$= \frac{5\ kg \times (9\ m/sec - 3\ m/sec)}{12\ sec}$$
   $$= \frac{5\ kg \times 6\ m/sec}{12\ sec}$$
   $$= \frac{30\ kg \cdot m}{12\ sec^2} = 2.5\ kg \cdot m/sec^2$$
   Force = 2.5 newtons.

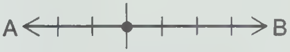
3. *In the first case, the force of 3 newtons being used to pull the cart is measured. In the second case, the 25-newton force measured is that of the earth's pull of gravity on the object. This measurement is the weight of the object.*

TEST YOURSELF *(p. 262)*

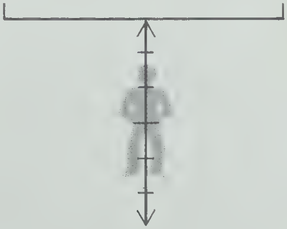
1. *Friction is an opposing force that is caused by the rubbing of surfaces.*
2. *Some possibilities are writing with a pencil, walking, stopping a bicycle, climbing stairs, tying a knot, climbing a tree.*
3. *Some possibilities are in pushing a car, in running a motor, between moving parts of machinery, while roller skating (except when trying to stop).*
4. *Friction can be reduced by (a) oiling one or both surfaces in contact, (b) making the shape of one object round—like a wheel.*

TEST YOURSELF *(p. 266)*

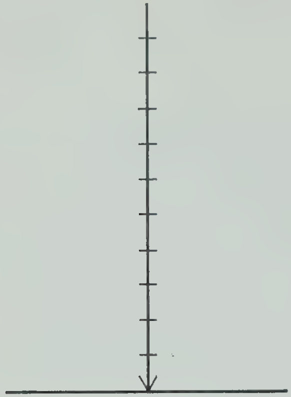
1. *Three lengths for team A represent 1500 newtons of force. Four lengths for team B represent 2000 newtons of force.*



2. *The scaffold and rope are exerting a force of 900 newtons on the man. Three lengths are equal to* that *force on the force arrow pointing up. Gravity is exerting a force of 900 newtons on the man. Three lengths are equal to* that *on the force arrow pointing down.*



3. *There should be 11 lengths on the force arrow pointing down to represent 550 newtons.*



TEST YOURSELF (p. 270)

1. *In figure 10•22 each section on each of the force arrows represents 100 newtons of force. In each situation, a 500-newton force is acting straight upward to oppose the downward pull of gravity on the box which weighs 500 newtons. By the way, notice that the total of the smaller forces is greater than the upward force exerted in each of the cases shown. Also notice that the amount of the smaller forces needed to maintain the same upward force increases as the angle between them increases. When the angle between them reaches 120°, each of the "smaller" forces is the same as the upward force.*

2. *When you hang with your arms straight up, the force on each arm is equal to half your weight. As you separate your arms, the upward forces exerted by your arms are acting at an angle to the downward force of gravity on your body. Therefore, the farther apart you place your arms, the more effort each arm must exert. (Note figure 10•22 for a force-arrow diagram of forces acting at several angles.)*

TEST YOURSELF (p. 274)

1. *The pull exerted is multiplied by the number of ropes used. The force on each rope is the same as the force on the end being pulled.*

2. *(a) Pulleys that are lifted with the object are moving pulleys. The pulleys attached to the top beam are fixed pulleys.*
   (b) Six

3. *More. The friction force is greater. The hooks rub against the rope as it is pulled instead of turning as a pulley does.*

TEST YOURSELF (p. 276)

1. *The force of gravity.*

2. *The product of force times the distance through which the force acts: work = Force × distance.*

3. *(a) According to the scientific definition, work has not been done.*
   (b) Work is being done. An object is being moved over a distance.
   (c) Work is being done. An object is being moved over a distance.

4. *If work = Force × distance, then work = 75 N × 5 m. Work =* 375 N•m. *(The force is the force of gravity on the block, or its weight.)*

5. *If work = Force × distance, then* 30 N•m *of work have been done.*

TEST YOURSELF (p. 279)

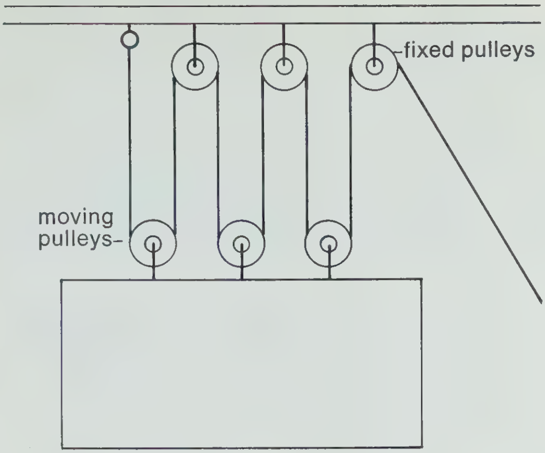
1. (a)
$$\text{Number of supporting ropes} = \frac{\text{weight of load}}{\text{force applied at free end}}$$
$$5 = \frac{2500\text{ N}}{?};\ ? = 500\text{ N}$$
Force applied at free end = 500 newtons

   (b)
$$\text{Number of supporting ropes} = \frac{\text{distance force applied at free end}}{\text{distance weight raised}}$$
$$5 = \frac{?}{4\text{ m}};$$ 20 m *of rope was pulled.*

   (c) Work = Force × distance
$$= 500\text{ N} \times 20\text{ m} = 10{,}000\text{ N}\cdot\text{m}$$

   (d) Work = Force × distance
$$= 2500\text{ N} \times 4\text{ m} = 10{,}000\text{ N}\cdot\text{m}$$

2. *(a)*



(b) Six

(c) Unknown: work output

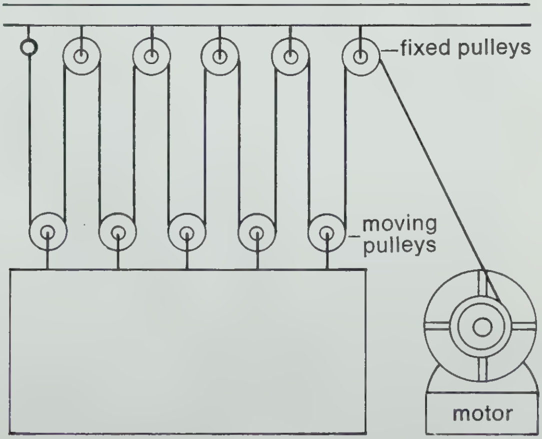
Facts: 6 uplifting ropes were used.
18 meters was the distance the force was applied at the free end.
1400 newtons is the weight of the load to be lifted.

$$\text{Number of supporting ropes} = \frac{\text{distance force applied}}{\text{distance weight raised}}$$

$6 = \frac{18\ m}{?}$; *Distance weight raised = 3 m.*

Work output = Force × distance lifted
$= 1400\ \text{N} \times 3\ m = 4200\ \text{N·m}$

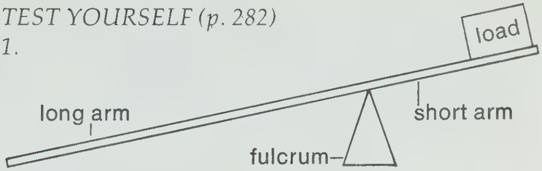
3. *(a)*



(b) Only 10 uplifting ropes. The 11th only changes the direction of the pull.
(c) 5 fixed pulleys
(d) 5 moving pulleys

TEST YOURSELF (p. 282)

1.



2. *Work input = work output*
Force applied to long end × distance long end moves = weight lifted × distance weight lifted:
$? \times 3\ m = 60\ \text{N} \times 2\ m$
$? = \frac{120\ \text{N·m}}{3\ m}$
Force applied to long end = 40 N

3. *Force × distance = Force × distance*
(input) *(output)*
$? \times 1.5\ m = 500\ \text{N} \times 0.5\ m$
Force = 166N *(weight needed at end of long arm to balance the 500 N at the end of the short arm)*

TEST YOURSELF (p. 285)

1. *An inclined plane is a flat surface used as a ramp or placed at an angle to another surface.*

2. *(a) Work output = weight of object × distance lifted*
= 200 N × 1 *m* = 200 N·m
(b) Work input = work output = 200 N·m
(c) Force × distance = work input
$? \times 3\ m = 200\ \text{N·m}$
You must apply 66 2/3 N *force.*

3. *Force × distance = Force × distance*
(input) *(output)*
$? \times 4.5\ m = 1350\ \text{N} \times 1.5\ m$
? = 450 N *Force*

4. *Force × distance = Force × distance*
(output) *(input)*
$? \times 2\ m = 550\ \text{N} \times 6\ m$
$? = 1650\ \text{N}$
The motor can haul a maximum weight of 1650 N.

TEST YOURSELF (p. 288)

1. $$\text{Mechanical advantage} = \frac{\text{Force output}}{\text{Force input}} = \frac{18\ N}{3\ N} = \frac{6}{1}$$
   $$= 6 \text{ to } 1$$

2. *Mechanical advantage of* 5 to 1.

3. $$\text{Mechanical advantage} = \frac{\text{distance force is applied}}{\text{distance weight is lifted}}$$
   $$= \frac{4\ m}{2\ m} = 2 \text{ to } 1$$

TEST YOURSELF (p. 289)

1. *(a) Work output* = 1700 N·m
   (b) Work input = 2000 N·m
   $$\text{(c) Efficiency} = \frac{\text{actual work output}}{\text{actual work input}} = \frac{1700\ N\cdot m}{2000\ N\cdot m}$$
   17 divided by 20 = 85% (efficiency of the pulley)

2. *(a) Actual work input is 500 N × 18 m = 9000 N·m.*
   Actual work output is 4000 N × 2 m = 8000 N·m.
   $$\text{Efficiency} = \frac{8000\ N\cdot m}{9000\ N\cdot m} = 89\%$$
   (b) 1000 N·m of work, or 11%*, were lost to friction.*

3. *Work output = 600 N × 2 m = 1200 N·m*
   Work input = 150 N × 10 m = 1500 N·m
   $$\text{Efficiency} = \frac{1200\ N\cdot m}{1500\ N\cdot m} = 80\%$$

TEST YOURSELF (p. 302)

1. *(a) The diver weighs 500 N and is on a platform 10 m high. Work = Force × distance*
   = 500 N × 10 m = 5000 N·m
   (b) The skier weighs 600 N and is on a hill 400 m high.
   Work = 600 N × 400 m = 240,000 N·m
   (c) The roller coaster weighs 24,000 N and is on top of a 30-m hill.
   Work = 24,000 N × 30 m = 720,000 N·m

2. *The ability to do work or the ability of something to move itself or some other object.*

3. *Light, electricity, and motion.*

TEST YOURSELF (p. 304)

1. *Newtons.*

2. *Force* changes *the speed of the object.*

3. *Near the earth's surface, the pull of the earth's gravity on an object stays about the same. If the object gets far away from earth's surface, the pull of the earth's gravity becomes less.*

4. *"The gravity force field of the earth" is the area on and around the earth in which a gravity force is exerted on an object.*

5. *You are applying a force equal to and in a direction opposite that of earth's gravity.*

6. *(a) A force was applied over a distance. Therefore, work was done on the nail by you.*
   (b) Your force had to be equal and in an opposite direction to the magnetic field of the magnet before work was done.

TEST YOURSELF (p. 307)

1. *Potential energy is the amount of energy an object would have if it were set in motion. It is a measure of an object's possibility for motion.*

2. *An object gets potential energy by being moved through a distance against a force field such as gravity.*

3. *Force × distance = potential energy*
   24 N × 4 m = 96 N·m

4. *Potential energy*

5. *Motion would result. The rock would be pulled to the earth's surface. The piece of iron would move toward the magnet. The north pole would move toward the south pole.*

6. *Force × distance = potential energy*
   850 N × 3 m = 2550 N·m

TEST YOURSELF (p. 309)

1. *Work = Force × distance*
   40 N × 3 m = 120 N·m of work was done
   70 N × 3 m = 210 N·m of work was done

The 70-N package would have the most potential energy.

2. *Yes. The package with a mass of 7 kg was pulled by gravity with the* same force per kilogram *as the package with a mass of 4 kg. Thus each kilogram, no matter which package it was in, was pulled by the same force through the same distance. For this reason each kilogram of mass increased in speed at the same rate. So both packages hit the ground at the same time.*

3. *The package weighing 40 N has a potential energy of 120 N•m. The package weighing 70 N has a potential energy of 210 N•m. The package with the greater potential energy will hit the floor with more "oomph."*

4. *Gravity caused the same increase in speed for both boxes through the first 2 meters. But one box fell 3 meters more. Gravity continued to cause an increase in the speed of that box through those 3 meters. So that box will be moving faster when it hits the floor.*

Heat

TEST YOURSELF *(p. 331)*

1. *No. Temperature is a relative thing. To have meaning, it must be compared with something else. If a person is used to temperatures such as –30°C (–22°F), 15°C (59°F) might be considered warm.*

2. *How much they expand when heated or contract when cooled.*

3. *It is easier to observe a temperature change in a liquid because a change in volume of a liquid is usually greater than that of a solid. The bulb at the bottom end of the thermometer is also important. The more liquid is in the bulb, the more expansion will be up the tube. The more expansion, the easier it is to read a change in temperature.*

TEST YOURSELF *(p. 333)*

1. *They are the melting point and the boiling point of pure water: 0°C (32°F) is the melting point; 100°C (212°F) is the boiling point.*

2. *Melting points and boiling points of pure substances remain the same. A thermometer calibrated with the melting point and boiling point of a pure substance as reference points will be the same as any other thermometer calibrated with the melting point and boiling point of that substance.*

3. *Use the enlarged C and F thermometer in figure 13•8. The temperatures are about* 99°F, 68°F, 158°F, *and* –40°F. *You can also get these answers by using the conversion formula,* $°F = 32 + 1.8°C$.

4. *Use figure 13•8. The temperatures are about* 29°C, 43°C, –7°C, *and* –18°C. *You can also get these answers by using the conversion formula,* $°C = \frac{°F - 32}{1.8}$

TEST YOURSELF *(p. 346)*

1. *They conduct heat so slowly that they feel as if they don't conduct heat at all.*

2. *Liquid crystal thermal paint changes color with changes in temperature. The color changes across the surface of the object as the temperature changes.*

TEST YOURSELF *(p. 353)*

1. *Equilibrium temperature is the point at which no heat is supplied from one substance to another.*

2. *A calorie is a unit of heat equal to the amount needed to raise the temperature of 1 gram of water 1°C.*

3. *If it takes 1 calorie to raise 1 gram of water 1°C, it takes 70 calories to raise 70 grams of water 1°C. The temperature of the water rose 35°C. 70 calories per °C × 35°C =* 2450 calories *were supplied to the cool water.*

4. *It takes 20 calories to raise 20 grams of water 1°C. So 20 calories per °C × 7°C =* 140 calories *must be supplied.*

5. *It takes 150 calories to raise 150 grams of water 1°C. The temperature rose (54°C − 42°C) 12°C. 150 calories per °C × 12°C =* 1800 calories *are needed.*

TEST YOURSELF (p. 362)

1. *The heat capacity of copper is 0.09 calories per gram per °C.*

$$\text{Heat capacity} = \frac{\text{heat given up or gained}}{\text{mass} \times \text{temperature change}}$$

$$0.09\ \text{cal/gm/°C} = \frac{?}{12\ \text{gm} \times 5\text{°C}}$$

$$0.09\ \text{cal/gm/°C} \times 12\ \text{gm} \times 5\text{°C} = 5.4\ \text{calories}$$

2. *The heat capacity of silver is 0.06 calories per gram per °C.*

$$\text{Heat capacity} = \frac{\text{heat given up or gained}}{\text{mass} \times \text{temperature change}}$$

$$0.06\ \text{cal/gm/°C} = \frac{?}{600\ \text{gm} \times 100\text{°C}}$$

Heat supplied to silver = 3600 calories

3. *The heat capacity of water is 1 calorie per gram per °C. The change in temperature of the 30 gram mass of water is 36°C − 20°C = 16°C.*

$$1\ \text{cal/gm/°C} = \frac{?}{30\ \text{gm} \times 16\text{°C}}$$

Heat gained by water = 480 calories.
The change in temperature of the unknown mass of water is 96°C − 36°C = 60°C.

$$1\ \text{cal/gm/°C} = \frac{480\ \text{calories}}{? \times 60\text{°C}}$$

$$1\ \text{cal/gm/°C} \times 60\text{°C} \times ? = 480\ \text{calories}$$

$$? = \frac{480\ \text{calories}}{1\ \text{cal/gm/°C} \times 60\text{°C}}$$

$$? = \frac{480\ \text{grams}}{60}$$

? = 8 grams of water at 96°C

4. *The heat capacity of water is 1 calorie per gram per °C. Thus it takes 50 calories to raise the temperature of 50 grams of water 1°C. The temperature of the water rose 5°C. It took 50 calories per °C × 5°C = 250 calories to raise the temperature of the water.*

The heat capacity of lead is 0.03 calories per gram per °C. The temperature of the lead changed 75°C.

$$0.03\ \text{cal/gm/°C} = \frac{250\ \text{calories}}{? \times 75\text{°C}}$$

$$0.03\ \text{cal/gm/°C} \times 75\text{°C} \times ? = 250\ \text{calories}$$

? = 111 grams of lead

5. *The heat capacity of silver is 0.06 calories per gram per °C. The temperature of the silver changed 45°C − 15°C = 30°C.*

$$0.06\ \text{cal/gm/°C} = \frac{?}{300\ \text{gm} \times 30\text{°C}}$$

$$? = 540\ \text{calories}$$

The heat capacity of water is 1 calorie per gram per °C. The temperature of the water changed 27°C.

$$1\ \text{cal/gm/°C} = \frac{540\ \text{calories}}{? \times 27\text{°C}}$$

? = 20 grams of water

TEST YOURSELF (p. 380)

1. 80 calories *is absorbed by each gram of ice when it melts.*

2. *When a substance freezes or changes from a liquid state to a solid state, it gives off heat equal to its heat of fusion.*

3. *Heat of vaporization is the amount of heat, in calories, needed to change 1 gram of a liquid to a gas.*

TEST YOURSELF (p. 385)

1. *Solids and liquids: If there is no temperature change, a solid keeps its shape. If there is no temperature change, a liquid takes on the shape of its container. Liquids and gases: If there is no temperature change, a liquid keeps the same volume though placed in another container. A gas always takes on the volume of its container.*

2. *Solids and liquids: If there is no change in temperature, both solids and liquids keep the same volume. Liquids and gases: Both liquids and gases take on the shape of their containers.*

TEST YOURSELF (p. 387)

1. *If the water is not moving, the ink slowly mixes throughout the water. It becomes a solution.*
2. *Hot tea*
3. *(a) Not a solution. (b) A solution. (c) A solution.*

Chemistry

TEST YOURSELF (p. 407)

1. *A substance is a pure material. Each molecule of any pure material has the same composition.*
2. *Determine the density (mass per unit volume) of each. Determine the melting point or boiling point of each. Determine how well the water solution of each conducts electricity. Other ways include determining (a) the heat of fusion, (b) the heat of vaporization (specific heat), and (c) how well each substance dissolves in water.*
3. *Melting point, boiling point, solubility in alcohol, heat of fusion, heat of vaporization, solubility in water, ability to conduct electricity, index of refraction, specific heat, and density.*
4. *Do* not *taste it.*
5. *It is difficult to get two amounts of powder exactly the same in volume. There are always spaces between the grains of powder.*

TEST YOURSELF (p. 411)

1. *Water can exist as a solid, a liquid, or a gas.*
   Its melting point is 0° Celsius.
   Its freezing point is 0° Celsius.
   Its boiling point is 100°C.
   Its heat of fusion is 80 calories per gram.
   Its heat of vaporization is 540 calories per gram.
   Its density is 1 gram per cubic centimeter.
2. *The liquid in the bottle looks like water. It is* not safe *to taste or smell a substance that is unknown.*
   (a) Determine the boiling point or freezing point of the liquid.
   (b) Determine the density (mass per unit volume) of the liquid and compare it with that of water.
   (c) Use a simple conductivity tester to find out how the unknown liquid conducts electricity as compared with water.
   (d) Add some of the unknown to water and see if it mixes.
   (e) Determine the heat of fusion and the heat of vaporization.
   (f) Determine the index of refraction.
   (g) Check all of this data with a table listing the physical properties of different substances. Do the physical properties of the unknown liquid match with those of water? If not, the liquid in the bottle is not water.
3. *Sodium bromide: melting point is 755°C, boiling point is 1390°C, and density is 3.203 grams per cc.*
4. *grams per cc (volume)*
5. *The index of refraction of sodium chloride is 1.544.*
6. *The density of sugar is 1.6 grams per cc.*

TEST YOURSELF (p. 418)

1. *The pure substance always melts completely at its established melting point. Mixtures usually melt over a range of temperatures.*
2. *If the mixture is a combination of several liquids and some solids, you might separate the substances in the following ways:*
   (a) Separate the solids from the liquids by using special filter paper.
   (b) Separate the denser liquid from the less dense liquid by just pouring off the top layer.
   (c) If the substances are dissolved in liquids, you can separate them from the liquids by a process that relies on change of state. This process is called fractional distillation.
   (d) Another way to separate a dissolved substance from solution is to allow the liquid to evaporate. This procedure is called crystallization.
3. *The fastest way to separate a solution of sugar in water is to boil off the water.*

TEST YOURSELF (p. 429)

1. *A chemical change is the change of one substance into another.*

2. *The following are some examples of chemical change or reaction:*
   (a) Limestone decomposes into carbon dioxide gas and calcium oxide when heated.
   (b) Phosphorus reacts violently with oxygen in the air.
   (c) Zinc reacts with an acid in solution and gas bubbles are formed.
   (d) Aluminum reacts with a base in solution and gas bubbles are formed.

3. *(a) Aluminum reacts with air.*
   (b) Aluminum reacts with sodium hydroxide (a base).

4. *Decomposition on heating is a chemical property of both sugar and limestone.*

TEST YOURSELF (p. 436)

1. *The following are three things you might observe when a chemical reaction is taking place:*
   (a) Bubbles form showing that gas has been produced.
   (b) There is a color change. For example, the sugar became a black mass when it was heated.
   (c) A precipitate forms. This happens when an insoluble substance is formed from a reaction between two solutions.

2. *The burning of gas in a stove is accompanied by a change of energy. Light and heat can be observed. Vinegar added to a solution of baking soda is accompanied by a change of energy. The container becomes cooler after the solutions are combined. The reaction uses heat energy supplied by the solution and the air around it.*

3. *Factors that might speed up chemical reactions are:*
   (a) Slowly or quickly changing the temperature of the reacting substances.
   (b) Changing the amount of surface area available for reaction.
   (c) Increasing the concentration of one substance.
   (d) Adding a catalyst.

4. *In a chemical reaction, the catalyst remains unchanged. This means it does not become a new substance or even part of a new substance.*

5. *An enzyme acts like a catalyst in the body. Enzymes help control the speed of chemical reactions in the human body.*

TEST YOURSELF (p. 467)

1. *Gold, silver, and platinum are not reactive metals.*

2. *Magnesium, aluminum, and manganese are reactive metals.*

3. *Metals that displace copper from a solution of copper sulfate are iron, magnesium, aluminum, manganese, zinc, chromium, cobalt, nickel, tin, and lead.*

4. *One metal that will not displace copper from a solution of copper sulfate (Table 1) is silver.*

TEST YOURSELF (p. 470)

1. *The parts of an electrochemical cell include: (a) a glass or plastic container, (b) 2 strips of different metals each placed in a solution of its own compound, (c) a porous cup containing one metal in its compound solution, (d) terminals attached to each metal strip, and (e) a wire (made of a substance that conducts electricity) connecting both terminals.*

2. *Using magnesium and silver metals will produce the highest voltage in an electrochemical cell.*

TEST YOURSELF (p. 485)

1. *The three methods of protecting iron against corrosion are:*
   (a) Galvanizing (coating) the iron with zinc.
   (b) Plating. Through electrochemical means, the iron is covered by a layer of another metal.
   (c) Painting. A coating of paint keeps the air and water from contact with the iron.

2. *Zinc protects iron better than tin does because zinc is a more reactive metal than iron. The zinc displaces the iron from iron ioxide (rust).*

3. *Corrosion is the process by which certain metals are worn away by chemical reaction with substances around them. Steel on automobiles rusts, or forms iron oxide, when it is exposed to oxygen in the air.*

4. *Plating is a process in which one metal is used to cover another metal by electrochemical means. Galvanizing is a process in which steel is coated with a thin layer of zinc.*

Do *not* write in the book. For true-false questions, give the complete word. For completion-type questions, give the best word or words. Discussion and research questions are in italics.

Light Unit

What Is Light? Part 1 (p. 11)

1. Isaac Newton's experiment using *two* prisms and sunlight showed that ________.
   (a) prisms add color to light
   (b) filters let through some colors but not others
   (c) the crystals of a prism are themselves made up of several different colors
   (d) light can be separated into colors and recombined into white light
2. (true-false) Newton showed that each color in light consisted of rays different from those of other colors.
3. (completion) Newton's theory stated that light was made up of invisible ________ in motion.
4. (true-false) According to Newton's theory, a green color filter lets through green light particles.
5. *A "theory" can be defined as an explanation for something that seems to keep happening under certain conditions. For example, you let go of a ball and you expect it to fall to the ground. You would probably pick the gravity theory to explain what happened. You could use the same "theory" to make a prediction in a similar situation. In this essay, a theory on light is given. Identify it. Explain how this theory could be useful.*

Seeing Red (p. 24)

1. According to the Young-Helmholtz theory of color vision, the color red is seen when the ________ .
   (a) receptor for that shade of red is stimulated
   (b) red receptor is stimulated and yellow and blue receptors are not
   (c) red receptor is strongly stimulated and the green and blue receptors are weakly stimulated
   (d) rods are strongly stimulated by the presence of red light
2. The three kinds of receptors generally thought to be basic to color vision are ________ .
   (a) red, green, and blue
   (b) red, blue-green, and yellow
   (c) orange, blue-green, and white
   (d) red, yellow, and blue
3. (true-false) If you stare at a red figure for a while and then quickly look at a white sheet of paper, you will see a faint red figure on the white paper.
4. Visual purple is built up in the eye in the ________ of light.
   (a) presence (b) absence
5. (true-false) It is possible to see yellow in the absence of yellow light.
6. *A friend of yours is having trouble "seeing" in the dark. What* might *be the cause?*
7. *Imagine that you took a pure red light and a pure green light and directed both onto a white surface. You would see a yellow spot. Explain what might be happening according to Hering's theory.*

Now You See It Now You Don't (p. 28)

1. In Land's experiments the filters placed in front of the camera *must* be ______.
   (a) the same as those used in front of the projector
   (b) red and green
   (c) different from one another in the band of color that passes through them
   (d) all of the above
2. The colors you would see in Land's experiments have been shown to be due to ______.
   (a) particles of light separated by a prism
   (b) stimulation of specific cones by colored light
   (c) rods reacting under dim light
   (d) none of the above
3. (true-false) In Land's studies, the brightness of different areas of the photograph is an important factor in determining the color seen.
4. (true-false) To duplicate Land's results, filters of yellow and blue may be used rather than red and green.
5. *The color you would see in Land's experiments is related to brightness values of that spot. Describe how the results of his studies differ from the Young-Helmholtz studies.*
6. *Draw a picture of Dr. Land's famous experiment. Be sure to label important parts of materials he used.*

What Is Light? Part 2 (p. 36)

1. (completion) Mirrors reflect better than sheets of paper because mirrors are ______ than paper.
2. (true-false) If light is scattered in many directions by a reflecting surface, the resulting image will be very clear.
3. (true-false) Images are seen clearly in mirrors when the angle of incidence of light equals the angle of reflection.
4. (true-false) When light from your face is scattered by a reflecting surface, you will be unable to see yourself in that surface.
5. *Name surfaces in which you have seen a clear or faint image of yourself. What is the one important feature of all the surfaces on your list?*

Mirror, Mirror on the Wall (p. 42)

1. The earliest mirrors known were made of ______.
   (a) aluminum (c) mercury
   (b) bronze (d) silver
2. The 16th-century glassmakers of Venice made mirrors by lowering a sheet of glass onto tin foil covered with ______.
   (a) aluminum (c) mercury
   (b) bronze (d) silver
3. (true-false) To prevent distortion, mirrors used in scientific instruments are silvered on the back.
4. *A window which looks like a mirror from the inside at night is probably aluminum-coated plastic. During the day, from the outside it is difficult to see into the building. Explain why this happens. Also, name at least one situation where this type of window might be useful.*
5. *Mirrors that are used to give accurate images are silvered on the top surface. Some astronomy telescopes are made this way. What other instruments might be made in the same way?*

Sunlight: Fuel for a Furnace (p. 50)

1. (completion) A furnace which gets its energy from the sun is called a ______ furnace.
2. (true-false) The light which reaches the concave reflecting surface of the solar furnace at Odeillo has previously been reflected by a flat mirror.
3. (true-false) The temperatures reached in the "oven" building of the solar furnace at Odeillo are high enough to melt steel.

4. (true-false) The energy produced in a solar furnace is small compared with the pollution caused by its operation.
5. *What may be some reasons why there are not many solar furnaces throughout the world?*
6. *What may be some other uses for the solar furnace besides melting metal?*

Another Kind of Curved Mirror (p. 52)

1. (true-false) A convex mirror is inwardly curved.
2. (true-false) The large mirrors used in stores to discourage shoplifting are convex.
3. (true-false) If a mirror produces an image which is much wider in scope than one seen with a flat mirror, the mirror is probably concave.
4. (true-false) The image seen in a convex mirror cannot be projected onto anything.
5. *Pretend you are at a fun-house in a carnival. How is your image distorted by the concave and convex parts of one of their mirrors?*
6. *If you wanted to burn a hole in a paper with a mirror, would you use a concave or a convex one? Why?*

What Is Light? Part 3 (p. 59)

1. (completion) When light from one opening interferes with light from a second opening nearby, the resulting effect is called ________ ________.
2. (completion) The effect of fuzzy edges on shadows is called light ________.
3. (true-false) The wave theory of light can account for data which the particle theory cannot explain.
4. (completion) According to the wave theory, colors differ from each other in ________ length.
5. (true-false) Diffraction effects in experiments with light are best explained by the particle theory.
6. *Newton and Young would agree that white light is made up of colors. On what points does Newton's particle theory disagree with Young's wave theory?*
7. *What were some factors that prevented Young's theory from being accepted?*
8. *Young made a comparison between the effects caused by water waves and some things he noticed about light. Describe or draw a mental model of the comparison he made.*

Zigzagging Light (p. 72)

1. (true-false) When a light beam's angle of incidence is perpendicular to a water surface, total internal reflection occurs.
2. (true-false) When a light beam strikes the water surface and is refracted parallel to that surface, the inner surface of the water acts as a mirror.
3. (true-false) Total internal reflection has been used to transport light through plastic wires.
4. (completion) The new way of bringing light from one place to another using total internal reflection is called ________ ________.
5. *You are looking up at the water surface as a fish would and you see a mirror-like image of the bottom of the pool. What is this phenomenon called? What causes it?*

What Is Light? Part 4 (p. 76)

1. Light travels ________ in air than in water.
   (a) faster (b) slower
2. (true-false) Refraction is explained better by the particle theory than by the wave theory.
3. (true-false) For Newton's particle theory to explain refraction, light must travel faster in other substances than in air.
4. (true-false) In certain situations, water waves bend in the same way as light does when it is refracted.

5. *In Newton's time no one had accurately measured the speed of light in air and in other materials. If you were to devise an experiment to solve this problem, what might you do? How did Fizeau and Foucault do it?*

6. *The speed with which light travels through various materials cast doubt upon which theory? Why?*

Lenses and Your Vision (p. 86)

1. The lenses in your eyes are ______.
   (a) concave (c) double-concave
   (b) convex (d) double-convex

2. In order to see clearly you must have eyes which focus the image on the ______.
   (a) iris (c) pupil
   (b) lens (d) retina

3. (true-false) When you look at an object moving toward you, your lenses become more curved.

4. (true-false) If the image on the retina is blurred, the iris will adjust the amount of light entering the eye until the image is clear.

5. (true-false) Convex lenses would be prescribed for persons who are far-sighted.

6. *Nearsighted eyes focus the image before it reaches the retina. To correct for this, what must glasses do to light before it reaches the lens of the eye? What kind of lenses in such glasses would be needed? Draw a diagram of a nearsighted and a farsighted eye. Show what happens to light entering the eye alone. Then show what happens with glasses in front of the eyes.*

7. *Your eyes are an important window to your general health. Even though you may not need corrective lenses, a regular eye check-up is a good idea. Early stages of many diseases have been observed by doctors just by looking through the lens of the patient's eye. What are some of these diseases?*

Other Seeing Aids: Microscopes and Telescopes (p. 92)

1. (true-false) Simple microscopes and telescopes are both generally made of two double-convex lenses.

2. (true-false) A double-convex lens more than one focal length away from an object will produce an upside-down image.

3. (true-false) Telescopes used to view distant scenes right-side up usually contain three different lenses.

4. (true-false) A double-convex lens less than one focal length from an object acts as a magnifier.

5. *A microscope and telescope have lenses which differ mainly in focal length. Why does the first lens in a microscope have a short focal length? Why does the first lens in a telescope have a long focal length?*

A Photographer at Work (p. 100)

1. (true-false) To focus a camera, the photographer sets the lens at the proper distance from the film.

2. (true-false) The camera shutter controls both the size of the light opening and the length of time it remains open.

3. (true-false) The *f*-stops on a camera are used to determine the size of the shutter opening.

4. (true-false) Shutter speeds are generally set at fractions of a second.

5. *You've taken a picture with a camera and discover that something went wrong. The photograph was too dark. According to this essay, what may have caused this effect?*

6. *Before you take a picture, what rules should you keep in mind? List them.*

7. *What other factors may affect the quality of your photographs besides those mentioned in the essay?*

What Is Light? Part 5 (p. 104)

1. (true-false) Max Planck's packet theory was more similar to particle theory than to wave theory.
2. (true-false) Heated objects give off light energy in a steady flow.
3. (true-false) With all the information available today on light, the particle and wave theories of light are still useful.
4. (true-false) Photons of red light have a different amount of energy than photons of blue light.
5. *Make a list of all the facts and generalizations you can about light. Then list several questions you may still have about light.*
6. *In the field of science, there is no right or wrong explanation for what happens in the world around us. One explanation may be better than another about certain things happening. Even that is continually subject to change. Scientists look at known facts collected through experimental research. Current theories may explain those facts, part of those facts, or none of those facts. Often, a new theory evolves based on a combination of the old. Such disagreement by scientists is an important part of their work. Would you agree or disagree that all theories are important to consider even if they seem to conflict, or create uncertainties? Support your answer with an example.*

Laser: Beam of the Future (p. 108)

1. (true-false) Artificial diamonds are usually used to make a laser.
2. (true-false) Lasers focus enormous energy with extreme accuracy.
3. (true-false) Laser light is incoherent.
4. (true-false) Light waves which are not in phase with those being reflected in the laser crystal are lost through the partly silvered end of the crystal.
5. *Identify from the essay what properties laser light has that ordinary light doesn't.*
6. *Can you add to the list of potential uses for laser light?*
7. *Which theory of light would best explain the behavior of laser light? Explain why.*

Our Visual Environment: Light or Blight? (p. 112)

1. (true-false) The appearance of the environment affects those who live in it.
2. (true-false) By carefully choosing the colors which surround us, we can create an effect of calmness or excitement.
3. (true-false) Billboards have been banned from some highways to preserve the beauty of the area.
4. (true-false) Building costs tend to determine the architectural style of public buildings today.

Electricity Unit

Those Were the Days (p. 131)

1. Ben Franklin's famous kite experiment showed that ______.
   (a) lightning was the release of an electrical charge from a storm cloud
   (b) metal rods, strings, keys, and silk ribbons would conduct electricity
   (c) electrical charges could be stored in certain types of clouds
   (d) static electricity was stored in certain types of clouds
2. Charles François DuFay found that objects with ______.
   (a) "vitreous" electricity attract each other
   (b) "vitreous" electricity attract objects with "resinous" electricity
   (c) "resinous" electricity attract each other
   (d) all of the above

3. (completion) In their experiments, Franklin used silk ribbon and DuFay used silk cords because silk acts as a (an) _______ .

4. A Leyden jar is used to _______ .
   (a) generate static electricity
   (b) generate current electricity
   (c) store electrical charges
   (d) store electrified glass

5. *Why should it be safer to remain in a car during a lightning storm than to stand at the front door of your house?*

6. *Certain synthetic materials, such as nylon, are excellent conductors of electricity. What have some clothing manufacturers done to eliminate the problem of "clinging"?*

The Shining Lights (p. 148)

1. In Edison's light bulb the part which glowed was the _______ .
   (a) metal post
   (c) powdered charcoal
   (b) carbon thread
   (d) platinum wire

2. Thomas Alva Edison's contribution to the development of the electric lamp was _______ .
   (a) making the first light bulb
   (b) using the first carbon filament made from paper
   (c) using argon to fill the space around the filament
   (d) making the first bulb that was both bright and long lasting

3. In modern light bulbs of the type ordinarily used in the home, the glow we see comes from the _______ .
   (a) carbon filament
   (c) nitrogen gas
   (b) tungsten filament
   (d) argon gas

4. (true-false) Colored light can be produced by passing electricity through various gases.

5. *Explain why the incandescent lamp invented by Sir Joseph Swan was not successful. Find out how long he worked on his invention. How long did Edison work on a similar problem? Why did it take them so long?*

6. *How would your everyday life change if suddenly there were no light bulbs or gas discharge lamps?*

Frog Legs and Other Things (p. 160)

1. While investigating Galvani's experiments on "animal electricity," Volta found that _______ .
   (a) lifeless frog legs generated an electrical charge
   (b) animal electricity caused movement in animal muscles
   (c) the solutions in the frog legs conducted electricity
   (d) all of the above

2. (completion) A type of battery used in physicists' laboratories since 1880 to provide a continuous source of electricity is the _______ .

3. A compass and a voltaic pile were used by Hans Oersted to show that _______ .
   (a) a wire carrying an electric current affects a magnet
   (b) compasses generate a small electrical charge
   (c) frog legs can carry electric current
   (d) the magnetism of the earth can be converted to electric current

4. Oersted's discovery stimulated the thinking of Ampère and led him to the conclusion that _______ .
   (a) the magnetism of the earth generates electric current
   (b) an electrified wire generates its own magnetic field
   (c) magnetic fields can be used to generate electric current
   (d) electrified wires can cause animal muscles to twitch

5. *Volta, Oersted, Galvani, and Ampère—all made important contributions to the study of electricity. Write a paragraph on each scientist's contribution.*

6. *Scientists refer to the earth as a large magnet. Give evidence that supports this idea. Can you generate an electrical current within that field?*

Messages by Wire (p. 172)

1. (true-false) Messages were sent and received by beating on hollow logs with sticks long before the telegraph was invented.
2. (true-false) The telegraph works by breaking and closing an electric circuit.
3. (true-false) By varying the amount of pressure on the key, the telegrapher is able to send the dots and dashes of the telegraph code.
4. (true-false) The vibrating diaphragm which was an important part of Bell's original telephone has been replaced by an electromagnet in modern phones.
5. *How many different jobs were affected by the invention of the telegraph? How many new types of jobs were created because of it?*
6. *Draw or describe how the telephone or the telegraph uses the principles of electromagnetism.*

Broken Circuits that Conduct (p. 176)

1. The "Edison effect" is _______.
   (a) the glow produced by an incandescent bulb
   (b) the increase and decrease in brightness over the life of an electric lamp
   (c) the movement of electric current across a vacuum from a heated filament to a metal plate
   (d) the one-way flow of electric current over the plate, grid, and filament of a triode
2. (completion) "Fleming's valve" with its one-way flow of electricity is known today as a (an) _______.
3. (completion) The difference between a diode and a triode is the presence of a third electrode called a (an) _______.
4. By adjusting the charge in a triode's grid one can _______.
   (a) prevent current from passing through the circuit
   (b) allow the triode to function as if it were a diode
   (c) control the amount of current in the plate-filament circuit
   (d) all of the above
5. (completion) Artificial crystals are combined to make a useful substitute for the vacuum tube. This substitute is called a (an) _______.
6. (completion) The semiconductor triode is commonly known as the _______.
7. *You can send a current through a semiconductor diode in only one direction, the negative to the positive. Explain why.*
8. *The semiconductor has had an important impact on the electronic industry. Look around your home. What new products are a result of this new discovery?*

Signals Without Wires (p. 183)

1. (true-false) Marconi invented a radio by which Morse code messages could be sent without wires.
2. (true-false) The purpose of a microphone is to amplify the signal to be transmitted.
3. (completion) The amplification of radio signals depended on Lee DeForest's invention, the _______.
4. (true-false) In the early 1900's, music was transmitted by mixing sound current with radio transmission current.
5. *The antenna connected to your television set picks up radio wave signals. Then what happens to these signals?*
6. *How did the invention of the radio make it possible for television to follow shortly?*

What's Behind that Electrical Outlet in the Wall? (p. 197)

1. (true-false) Moving a magnet in and out of a coil of wire produces an electric current.
2. (true-false) Power plants are more likely to be located inland than near bodies of water.
3. The electrical energy produced in power plants is ______ and ______.
   (a) high amperage . . . high voltage
   (b) high amperage . . . low voltage
   (c) low amperage . . . low voltage
   (d) low amperage . . . high voltage
4. The increase or decrease in voltage produced by a transformer depends on the ______.
   (a) number of loops in the wire coils
   (b) choice of metals used to build it
   (c) type of energy which operates the turbines
   (d) distance between transformers
5. *Draw a diagram and name the parts of an* alternating-current generator. *Draw a diagram and name the parts of a* direct-current generator.
6. *Briefly describe the three main kinds of power plants in use. Find out which kind supplies your home with electrical power.*
7. *Read your appliances. Do most of them use an alternating-current or a direct-current form of energy?*

Who Gets the Credit? (p. 204)

1. (true-false) Faraday's motor used a moving wire to produce electrical current.
2. (completion) Wrapping insulated coiled wire around an iron core and connecting the coil to a power source produces a (an) ______.
3. A magnet moving in relation to fixed wire coils produces an electric current and, therefore, is a simple type of ______.
   (a) motor (c) generator
   (b) engine (d) vacuum
4. (true-false) Alternating current fell into disuse in the United States because the inventions of Edison ran more simply with direct current.
5. (true-false) Once uses were found for the motor, scientists went on to invent the generator.
6. *How did Faraday "convert magnetism into electricity"? What did he do differently from Ampère? (See essay p. 160.)*
7. *Make a time-line drawing or description of the development of the electric motor. Include some interesting points about each scientist and his work.*

Power Controversy (p. 214)

1. (true-false) Building dams results in sources of electric power without damage to nature.
2. (true-false) Nuclear power plants are pollution-free as long as radioactivity does not escape.
3. (true-false) Burning coal to produce electric power would be a desirable method if our supply of coal were unlimited.
4. (true-false) If the discharge of heated water into lakes and streams becomes common, it may affect the weather over nearby land areas.

Motion Unit

Tick Tock (p. 232)

1. (completion) The rhythms of your heartbeat and breathing are referred to as ______ clocks.
2. (completion) The cycles of day and night and the phases of the moon are called ______ clocks.
3. Which one of the following was used by the Egyptians to make huge shadows in order to measure short intervals of time?
   (a) sundial (c) stick
   (b) water clock (d) obelisk

4. (completion) The ancient Egyptians first kept records of the position of the ________ in order to predict when the Nile would flood.

5. Galileo's observations of a ________ helped make the clocks of his time more accurate.
   (a) pendulum (c) spring
   (b) weight (d) balance

6. *Is there any way you can think of to measure time without using motion?*

7. *Explain what would happen all over the world if our present systems for measuring the passage of time were eliminated. For example, how would the airlines be affected?*

How Much Depends on Where (p. 242)

1. The decimal system is based on factors of ________.
   (a) 2 (c) 12
   (b) 10 (d) 100

2. (true-false) The metric system is the measuring system most commonly used throughout the world.

3. (true-false) The only measuring system made legal by the Congress of the United States is based on the inch, foot, and yard.

4. Which one of the following terms is used in the metric system?
   (a) peck (c) rod
   (b) furlong (d) kilogram

5. *If the United States were to go completely metric within the next five years, how would events be described? For example, in a football game your team has a touchdown after the player runs 40 yards. How far is that in meters? Give some examples from other sports.*

6. *What are some of the reasons the rest of the world uses the metric system?*

Up, Up, and Away (p. 292)

1. The part of a crane which balances the load to be lifted is called the ________.
   (a) counterweight (c) arm
   (b) buffer (d) tower

2. (true-false) Elevators today generally use a pulley and counterweight system similar to that used in the late 1800's.

3. (completion) The crane is a combination of two simple machines, the pulley and the ________.

4. (completion) A device for moving people from one level to another which is basically an inclined plane is the ________.

5. *Cranes, elevators, and escalators—all are a collection of simple machines. What are some of these* simple *machines? Give examples of other complicated-looking machines which are really a collection of simple machines.*

6. *Why do you think an escalator might be a better way to move people than an elevator? What would be some of the disadvantages?*

Heave-Ho (p. 295)

1. (true-false) The great blue stones used in building Stonehenge were quarried nearby and relatively little transportation of materials was required.

2. (true-false) The builders of Stonehenge probably knew how to move heavy objects by using log rollers.

3. (true-false) The wooden machine, used by Egyptians today to lift heavy objects, may be similar to ones used in constructing the pyramids.

4. (true-false) The writings on the walls of the pyramids give us important clues to the methods of construction used in ancient times.

5. *Make up a theory about how you think Stonehenge was built. Explain how the type of tools available at that time were used and how people moved the massive stones. (Hint: Would building a mountain of earth help to move the stones?)*

6. *How did the people who settled the Western United States build log cabins and houses? What type of tools did they use and how?*

The Invisible String (p. 311)

1. (true-false) Scientists today would agree that any falling object would increase in speed at the same rate as any other object if we subtract the difference caused by air resistance.
2. The person who first suggested that the sun and all the planets were affected by invisible forces pulling toward each other was ______.
   (a) Aristotle (c) Newton
   (b) Galileo (d) Leibniz
3. (true-false) Leibniz agreed with Newton that an applied force can change an object's motion, even if there is no contact between the force and the object.
4. (true-false) Galileo's theories concerning objects falling in a vacuum were confirmed by astronauts' experiments on the surface of the moon.
5. *Take a survey. Ask several people to predict what will happen if objects of two different masses are dropped from the same height at the same time.*

   Compare your results with other members of the class. How many people in your survey still agree with Aristotle? How many agree with Galileo?
6. *Most scientists agree on the effect of gravity on objects near earth's surface. What is that effect? Explain how this force is a predictable one.*

A Backward Shove When Going Forward (p. 315)

1. (completion) An object falling freely toward earth increases its speed each second about ______ meters per second.
2. (completion) If you are riding in a spaceship which is increasing its speed away from earth each second at a rate of 20 meters per second, the force you feel is computed to be ______.
3. (true-false) Mathematically, g is calculated by dividing the force on the object by the object's mass.
4. (true-false) When an object is falling freely, the force on it is equal to its weight.
5. *Define what the symbol* g *means.*
6. *Suppose a racing car is speeding up to 2* g*'s. In metric units, how much is the car speeding up each second?*

What's the Hurry? (p. 318)

1. (true-false) The average speed of traffic in New York City is slower today than in 1911.
2. (true-false) Although air travel is quick, travel time is greatly increased by traffic-jams on the ground.
3. (true-false) According to Cousteau, the speedy and powerful pleasure boats of today are a bigger contributor to water pollution than oil spills.
4. (true-false) Many people are turning to forms of recreation such as bicycling, sailing, and mountain climbing because these activities *do not* use up the earth's resources and are relatively pollution free.

Heat Unit

Thermometers and How They Got That Way (p. 334)

1. What is the major deficiency of Fahrenheit's early thermometer?
   (a) the steps on the scale were not equal
   (b) the boiling point of water was not 100°
   (c) the reference points were items which varied
   (d) the glass tube held too much alcohol
2. Match each of the following scientists to his work. Celsius ______; Fahrenheit ______; Galileo ______; Newton ______.
   (a) first used purified mercury in the thermometer tube

(b) first calibrated an alcohol thermometer from the freezing point of salt water
(c) first chose reference points for thermometers
(d) first attempted to measure temperature
(e) first used freezing and boiling points of pure water as reference points

3. (true-false) Normal human body temperature is set at 98.6° because Celsius used it as one of the three reference points on his scale.

4. (completion) The thermometer which was divided into 100 equal parts was developed by ______.

5. *Often one scientist will improve on another's work. The result can be an important breakthrough. Give an example from this essay.*

6. *What could a weather forecaster say about temperature if a standard thermometer was not available?*

Is There Another Way? (p. 338)

1. The temperature measuring device which works because unlike metals produce a small voltage when they touch is called a (an) ______.
   (a) thermocouple
   (b) thermograph
   (c) resistance thermometer
   (d) optical pyrometer

2. A platinum wire coil is a basic part of a temperature measuring device called a (an) ______.
   (a) thermocouple
   (b) thermograph
   (c) resistance thermometer
   (d) optical pyrometer

3. Match the measuring device with the type of object it is used to measure. Thermocouple ______. Thermograph ______. Optical pyrometer ______. Resistance thermometer ______.
   (a) objects hot enough to give off light
   (b) skin temperature
   (c) air in smoke stack
   (d) air inside a refrigerator

4. (true-false) A resistance thermometer is especially useful when temperatures must be accurately measured inside machines.

5. (completion) The thermograph is used to take a photograph called a ______.

6. *Various temperature measuring devices are used in many ways. Make a list of situations where temperature control is important. Which type of device mentioned in this essay would you use in one of your situations?*

7. *You might be able to read thermometers without knowing how they work. But why is it important for an engineer to know basic ideas from other areas of science? For example, how could a knowledge of optics or chemistry help him or her in using various thermometers?*

Calories You Eat (p. 354)

1. (true-false) The Calories in food each = 100 ordinary calories.

2. (true-false) To accurately determine the number of Calories in a particular French fry, it would be necessary to destroy it by burning under controlled conditions.

3. (completion) The instrument used to determine the number of Calories in a food is a ______.

4. Which one of the following snack items is lowest in number of Calories per serving?
   (a) pizza (c) apple pie
   (b) chocolate cake (d) doughnut

5. *Compare the fuel to run the human "engine" with that used to run a car. For example, which fuel is used more efficiently?*

Pots and Pans and Other Things (p. 363)

1. (true-false) Metal pans conduct heat better than ceramic pans.

2. *To avoid* uneven heating you might use a ______ frying pan.
   (a) metal (b) ceramic

3. Which one of the following is *not* an advantage of wood window frames when compared with those made of metal?
(a) wood has heating properties similar to brick and plaster
(b) wood does not conduct heat so easily as metal
(c) wood expands very little when heated
(d) wood contracts to keep out the cold

4. (true-false) Special alloys are used in the construction of metal buildings to increase the expansion and contraction of metals.

5. To create a house which would be naturally cool in summer and warm in winter the best material to use would be ______.
(a) wood (c) stone
(b) glass (d) steel

6. (true-false) Insulation helps keep houses warm in winter and cool in summer by trapping air so it cannot move about.

7. *Explain which is better to cook with, a copper pan or an iron pan? (Note: heat capacity of copper is 0.09 and of iron is 0.11)*

8. *Which is a better conductor of heat, a glass or brick material? Describe one way to test your prediction.*

Heat Engines (p. 366)

1. The steam engine was developed because of a need for a better way to ______.
(a) pump water from mines
(b) generate electricity
(c) propel ships and land vehicles
(d) heat large factories

2. (completion) That portion of a steam engine which moves when steam presses against it is called a ______.

3. (true-false) The internal combustion engine is a type of reciprocating engine.

4. (completion) Today, steam turbines are most often used to ______.

5. (true-false) Rocket engines are basically very efficient reciprocating engines.

6. *What other reasons might there be for work-saving inventions, like the aeolipile, to remain merely "toys" for many years?*

7. *Determine whether or not the following phrase adequately describes this essay: "Necessity is the mother of invention." Explain your answer.*

Water—Great Stuff! (p. 381)

1. Ice floats in water because it ______.
(a) contains pockets of trapped air
(b) has a very low capacity to absorb heat
(c) expands when it freezes
(d) continually melts around the edges

2. The most common way to purify water which has substances dissolved in it is to ______.
(a) freeze it and remove the impurities
(b) treat it with chemicals
(c) filter out all the unwanted substances
(d) change it to a gas and then to a liquid

3. (true-false) Water absorbs and releases less heat than most substances so it is sometimes used to cool machinery.

4. (true-false) It is difficult to break down water into hydrogen and oxygen.

5. *Ice has a high heat capacity and a high heat of fusion. How is this useful in many "industrial processes" that require a "cooling agent"?*

6. *How many ways was water used by you in one day? Make a list.*

7. *Someone told you that there is life, as we know it, on the moon. What reason(s) would you give for not agreeing with the theory?*

There Is a Model (p. 388)

1. (completion) Regularly shaped pieces of pure substances with angles and flat surfaces are called ______.

2. (completion) When pollen grains are suspended in water, the type of movement they show is called ______.

3. Which one of the following types of molecules moves most rapidly?
   (a) gas (c) solid
   (b) liquid

4. (true-false) Since crystals of sugar have flat faces which come together at right angles, we know that the molecules are arranged in a similar pattern.

5. When two substances are of different temperatures, the energy in transfer between them is called ______.
   (a) heat (c) fusion
   (b) Brownian motion (d) molecular motion

6. (true-false) When you heat a substance, its molecules move more rapidly.

7. *You made a bet with a friend. You said you could show how gas molecules move faster than liquid molecules. What will you do to prove your claim?*

8. *To date, the molecular structure of matter theory has been very useful. It has helped explain certain phenomena, for example, melting ice. Name other phenomena the theory might explain.*

WATER . . . Water . . . water (p. 394)

1. The major difficulty in converting salt water to fresh water is ______.
   (a) periodic salt water shortages
   (b) moving workers to coastal locations
   (c) technical problems in processing
   (d) excessive costs

2. Sea water is converted into fresh water most commonly by ______.
   (a) distillation
   (b) filtration
   (c) freezing
   (d) evaporating

3. (true-false) The scale that builds up on pipes in a desalting plant is caused by the salts in sea water.

4. (true-false) The transportation of desalted water can add considerably to its cost.

Chemistry Unit

Gasoline and Peppermint (p. 419)

1. In distilling petroleum a major piece of equipment used is a ______.
   (a) vaporizing column
   (b) fractionating column
   (c) steam plate
   (d) steam separator

2. Inside the metal towers used in distilling petroleum, substances separate according to ______.
   (a) boiling points (c) density
   (b) water pressure (d) mass

3. (true-false) Less heat is needed to boil a liquid in low-pressure distillation than under higher pressures.

4. (true-false) Steam passed through a liquid such as peppermint oil causes vapors to escape at lower temperatures than usual.

5. *How is the distillation of crude petroleum similar to that of peppermint oil?*

6. *Describe what might happen if our sources of petroleum were sharply cut off or limited to twenty years.*

From Aspirin to Fake Gems (p. 422)

1. (completion) The basic difference in the structure of glass used in cookware and that used in windows is the presence or absence of large numbers of ______.

2. (completion) Sand is to a pearl as titanium oxide is to ______.

3. (true-false) Artificial rubies and sapphires are made of thousands of tiny crystals formed in layers on a seed crystal.

4. (true-false) Synthetic gems are chemically identical to natural ones.

5. *The process of crystallization is often used to purify products. In what way is this process different from that of distillation? (See essay page 419.)*

6. *The crystallization of aspirin is slightly different than that of ceramic glass and synthetic gems. Explain the difference in the manufacturing of each product.*

A Molecular Demolition Derby (p. 438)

1. (true-false) Chemical reactions occur when molecules crash and break apart and then combine in a new way.
2. (true-false) Decreasing the temperature makes molecules move faster and so speeds up a chemical reaction.
3. The more molecules of a substance that are in a solution, the ______ the reaction.
   (a) faster (b) slower
4. (true-false) Catalysts can be used to help control the speed of a chemical reaction.
5. *You are observing a chemical reaction take place. You have just added an unknown substance to water. What might you see that would lead you to believe that the "crashes" between molecules are violent in this reaction?*

The Story of the Atom Part 1 (p. 440)

1. Which one of the following men was the first to teach that matter was composed of earth, water, air, and fire?
   (a) Aristotle (c) Democritus
   (b) Pythagoras (d) Socrates
2. Who was the man who introduced the concept of the atom?
   (a) Aristotle (c) Boyle
   (b) Democritus (d) Dalton
3. In modern times a complex substance such as water is called a (an) ______.
   (a) compound (c) particle
   (b) hyle (d) element
4. (true-false) Democritus chose the term *atom* to describe a particle which could not be divided.
5. (true-false) A molecule can never contain a fractional part of an atom.
6. *Before the acceptance of modern atomic theory, matter was scientifically defined in several ways. Make a time line showing how matter was viewed through the centuries.*
7. *Imagine you are sent back in time when Aristotle's theories were accepted as* the *explanation for all "matter." What kind of equipment might have been available for experiments? What might have been the attitude toward scientists and their work by persons of influence? Why do you think Aristotle's theory was popular at that time?*

The Story of the Atom Part 2 (p. 445)

1. (true-false) Elements can be grouped according to the chemical reactions in which they occur.
2. The man who organized the elements into the periodic table was ______.
   (a) Boyle (c) Berzelius
   (b) Dalton (d) Mendeleev
3. (completion) The proton of the hydrogen atom is located in its ______.
4. The negatively charged particle in the outer area of the atom is called the ______.
   (a) proton (c) neutron
   (b) electron (d) hydron
5. (completion) Nearly all the weight of the atom is located in its ______.
6. (true-false) In each atom the number of protons plus electrons equals the number of neutrons.
7. *Describe the difference between the atomic weight and the atomic number of an element.*
8. *Draw a model of an atom and label its parts.*

"Who-dun-it?" (p. 449)

1. (completion) People trained to use science to solve legal problems are called ______ scientists.
2. To find which elements are present in a paint sample one would generally use the ______.

(a) emission spectrograph
(b) index of refraction
(c) precipitin test
(d) benzidine test

3. To tell human blood from animal blood, one can use a test which will show the difference between their ________.
(a) peroxidases (c) blood types
(b) proteins (d) acids

4. A mixture of hydrochloric acid and copper chloride is used to ________.
(a) distinguish human from animal blood
(b) restore writing removed with ink eradicator
(c) read original serial numbers on metal surfaces
(d) identify metallic poisons which concentrate in hair

5. *In this case, how many pieces of evidence to be presented in court can be traced back to some scientific test?*

6. *Describe other tools or techniques used by forensic scientists besides those listed in the essay. For example, how is ultra-sound or identification by smell being used?*

7. *What other important characteristics must a forensic scientist have besides knowledge of the field?*

From Atoms to Ions (p. 472)

1. (completion) Atoms which have become electrically charged are called ________.

2. When a strip of zinc is placed in a solution of copper sulfate, what is deposited on the strip?
(a) copper atoms (c) electrons
(b) zinc atoms (d) neutrons

3. (true-false) When zinc ions go into solution, they are electrically neutral.

4. (true-false) The electrochemical cell provides a current until all the zinc is used up or there are no more copper ions left.

5. *The atom does not always remain "neutral." What causes an atom to lose its neutrality? Give an example of such a reaction.*

6. *Draw a model of what happens in an electrochemical cell. Explain how a chemical reaction produces an electric current.*

7. *Make a list of batteries you use in everyday life. Are all the batteries on your list examples of displacement reactions? Explain.*

From the Stone Age to the Foundry (p. 475)

1. The first metal used to any extent in the making of tools and weapons was ________.
(a) copper (c) lead
(b) tin (d) iron

2. (true-false) Fire was used by the ancients to crack the rock walls in the copper mines.

3. (true-false) Many bronzes contain tin.

4. What does iron from meteorites contain that smelted iron does not?
(a) copper (c) nickel
(b) bronze (d) gold

5. (true-false) Quenching produces steel which is strong and flexible.

6. *Copper smelting was used long before iron smelting. Why?*

7. *In this essay, how many times was the discovery of a metal or its use a chance happening? Can you name any other ones?*

8. *How might the supply of metals and knowledge of their uses have affected the development of ancient cities? Is this still an important factor today? Give an example.*

The Magic of Carbon (p. 488)

1. (completion) Organic chemists study the compounds which contain the element ________.

2. (true-false) It is possible for two molecules to have the same number of atoms of two or more elements and yet be different substances.

3. (true-false) Mineral compounds usually contain chains of carbon atoms.

4. (completion) Compounds which contain only carbon and hydrogen are called ______ .

5. *What is the major difference between the compounds in living things and compounds in minerals?*

6. *Carbon atoms link to each other. How does this linking relate to the variety of living things?*

Molecules on a Chain (p. 490)

1. (completion) Large molecules which are made of units of smaller molecules are called ______ .

2. (completion) Excess sugar in the human body is changed chemically into fat or polymerized and stored as ______ .

3. A polymer of sugar which cannot be digested by humans is ______ .
   (a) glycogen
   (b) wool
   (c) starch
   (d) cellulose

4. (completion) Proteins are made of combinations of simple molecules called ______ .

5. (true-false) Fur coats and leather shoes are made of cellulose.

6. (true-false) Wood is made of sugar molecules.

7. *Name two polymers that plants form. Give examples of two foods we eat that contain cellulose molecules. What happens to these molecules in our bodies?*

8. *Make up a menu for those regions of the world where there is a lack of animal protein in the diet.*

Synthetic Polymers (p. 496)

1. Which one of the following was the first synthetic polymer?
   (a) glycogen
   (b) celluloid
   (c) nylon
   (d) rayon

2. (true-false) Most synthetic polymers are chemically reactive.

3. (true-false) Synthetic polymers have been made in laboratories for over 100 years.

4. (true-false) Many synthetic polymers are not biodegradable.

5. *Make a chart showing natural polymers and synthetic polymers. Which list is longer? How would your chart look if it were made 100 years ago?*

6. *What are some useful physical and chemical properties of synthetic polymers? What are some properties of these polymers which may be harmful to humans?*

The Fly in the Ointment (p. 498)

1. Many packaged foods contain added preservatives. The major objection to this practice is that ______ .
   (a) in rats some preservatives cause birth defects
   (b) the testing of the effects of preservatives on humans is inadequate
   (c) many people are sensitive to preservatives and may suffer discomfort from them
   (d) stronger concentrations may be needed in the future to prevent disease

2. Mercury found in streams is dangerous to humans because ______ .
   (a) it is concentrated in our food chain
   (b) it may get into supplies of drinking water
   (c) heavy metals are very poisonous when diluted
   (d) mercury is deposited in human fat

3. (true-false) The effect of DDT on the health of humans is unknown.

4. (true-false) The pollutants in the air, such as nitrogen oxides and hydrocarbons, react in the presence of sunlight to produce smog.

5. *How do your daily habits help put toxic elements into your environment?*

6. *The government ban on the use of cyclamates in food was partly based on research with rats. Why is research done on rats often used as a comparison with what could happen to humans? How much importance should the results of such research be given in situations where people do not agree? Explain.*

The Good Old Way (p. 507)

1. (true-false) The movement of people to the cities has been balanced by the increased food production of those remaining on the farm.
2. (true-false) Hybrid corn and wheat seed have increased the production per acre.
3. (true-false) Nitrogen fertilizers added to the soil increased the use of crop rotation and decreased the need for insecticides.
4. (true-false) The development of herbicides changed the method of killing weeds in the fields.

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Chapter 2. *p. 32* Clinton Bond/BBM Associates. *p. 33 top:* Scott, Foresman Photography Dept. *p. 37* drawings by Scott, Foresman Art Dept. *p. 42* Hirmer Fotoarchiv Munchen. *p. 43* Bibliotheque Nationale, MS. Fr. 12420 f. 101v. *p. 51 top:* Claude Gazuit of Rapho Guillumette Pictures; *bottom:* drawing courtesy French Embassy. *p. 52* Scott, Foresman Photography Dept.

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